GEOMORPHIC RESPONSE TO RESTORATION AND DISTURBANCE: GRAZING, FIRE, AND FLOODING ON THE MIDDLE FORK JOHN DAY RIVER, OR

by

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Salmon habitat restoration is ongoing at a Nature Conservancy preserve on the Middle Fork John Day River in the Columbia River Basin in north-central Oregon. The site has a long history of disturbance including dredge mining upstream, channelization, grazing, logging, fire, and floods. Using historic aerial photos, habitat unit surveys, and cross sectional profiles, this thesis shows how the channel morphology, particularly habitat unit diversity, has changed since 1939, just before placer mining began. Results show that the dominant influence on present day channel morphology is channelization from the 1930’s. Other changes including dredge mining in the late 1930’s to early 1940’s, cessation of cattle grazing in 1991, and a fire followed by a flood in the winter of 1996-1997, had less impact because of the straightened, stabilized channel morphology.

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CHAPTER I

INTRODUCTION

The Middle Fork of the John Day River, situated in the Columbia River Basin in north central Oregon, is part of the second longest free flowing river in the contiguous United States (Figure 1). Since it has never had hatcheries on it, it is an important resource in the recovery of wild anadromous and residential salmonid fish. Bull trout and summer steelhead which are currently listed as threatened species under the Endangered Species Act and spring chinook all use the Middle Fork during the spawning and rearing stages of their life cycles. The decline of anadromous fish populations in the Pacific Northwest has been attributed to harvesting and habitat degradation (NOAA, 2006), primarily as a result of dam building for hydroelectric power, but also grazing of livestock and resource extraction such as logging and placer mining. Such disturbances have impacted the present day availability of suitable salmon habitat on the Middle Fork John Day River.

The spawning and rearing stages of a salmon's life cycle require a diversity of hydraulic conditions which are best provided by a highly pronounced riffle-pool sequence (Lisle, 1982). It has been shown that heavy sedimentation increases the spacing between pools, decreasing the amount of effective salmon habitat (Lisle, 1982). Sedimentation can increase in rivers naturally as a result of large floods and debris flows. This can be exacerbated when the vegetation that holds back sediment is removed by fire (Agee, 1990; Wittenberg and Inbar, 2009) and grazing (Elmore and Beschta, 1987; Gunderson, 1968).

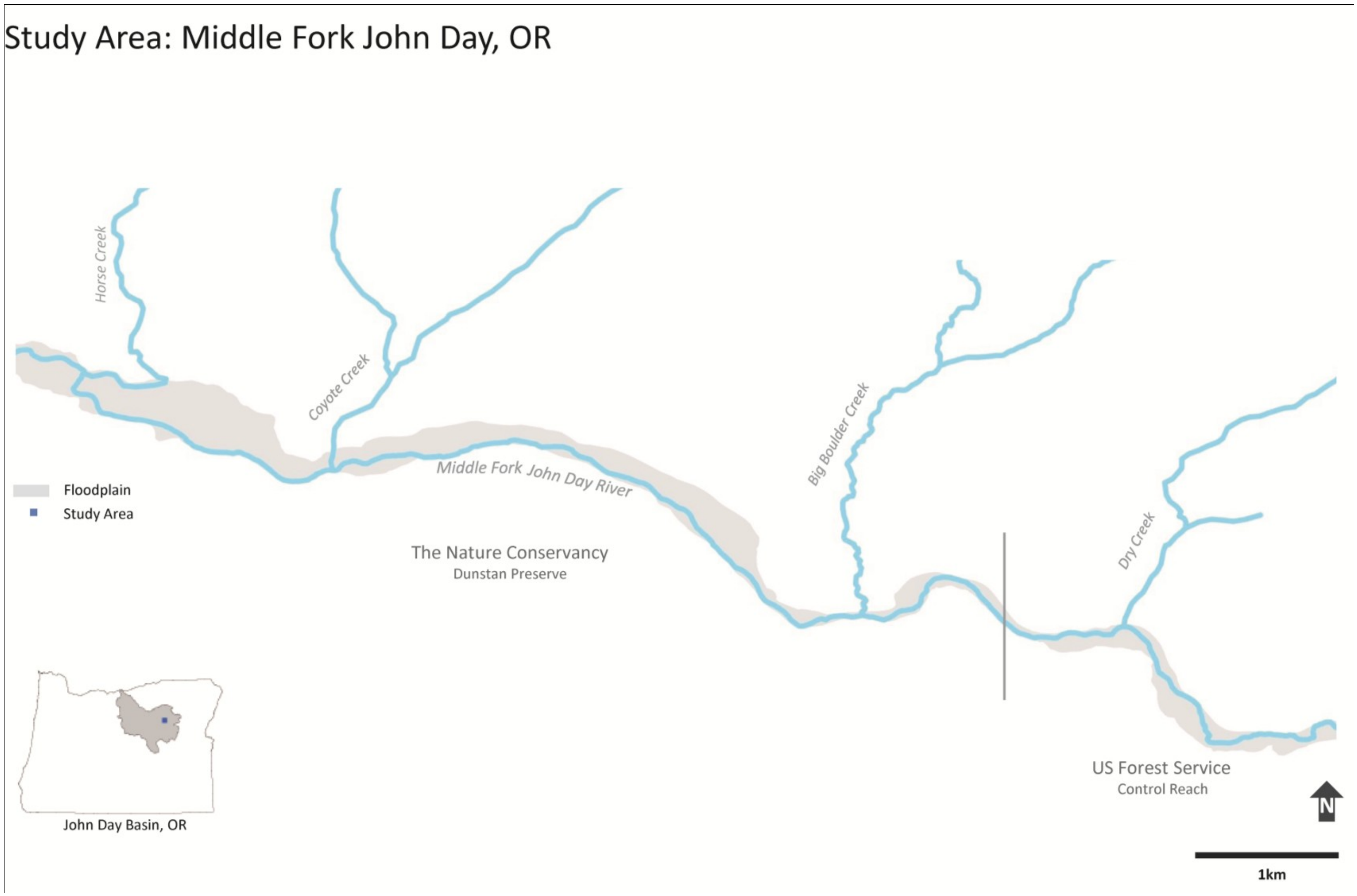


Figure 1: Study area showing the property boundary between The Nature Conservancy preserve and the U.S. Forest Service control reach. Flow is from right to left

Dredge mining, for example, has historically played a large role in the degradation of habitat on the John Day. In the 1930s through the early 1940s placer deposits of gold along portions of the Middle Fork were dredged, altering the physical and chemical environments that both terrestrial and aquatic organisms depend on (Figure 2). Today, land use including logging, grazing, and road building continues to impact the Middle Fork (Oregon Water Resources Department, 1986; Torgersen, et al., 1999).

Because of the importance of the Middle Fork John Day River for salmon habit recovery, The Nature Conservancy (TNC) purchased the 1,200 acre Dunstan Homestead property (Figure 1) with the intent of restoring natural flows and vegetation to the surrounding floodplain (Clair and Fields, 2004). The property was acquired in 1991, and by 2000 they began actively restoring the channel. The purpose of this restoration has been to reverse the degradation that resulted from the area's long history of grazing as well as dredge mining that occurred upstream of their property throughout the 1940s (The Nature Conservancy, 2009). Another more recent impact was the 1996 high severity Summit Fire that burned 37,986 acres. The fire burned along the hill slope and jumped the channel on the TNC property. This was followed by a large flood event in the winter of 1997. The largest flood occurred on Jan 30, 1965 with a peak discharge of 4360cfs (USGS National Water Information System, 2009). The 1997 flood had a peak discharge of 3930cfs which was 730cfs higher than the third largest flood. Typical annual peak discharges are between 2,000 to 3,000cfs (USGS National Water Information System, 2009). Water draining off the burned area runs into Big Boulder Creek, a tributary of the Middle Fork John Day River.

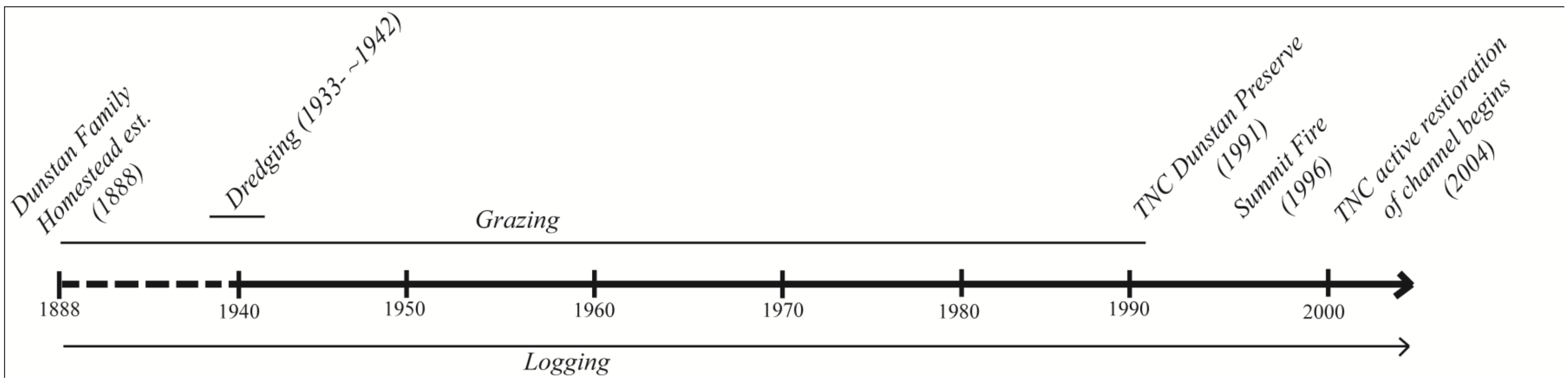


Figure 2: History of disturbance on and around the Dunstan homestead property.

Focusing on the Dunstan Preserve, this study seeks to understand how the channel morphology, particularly habitat unit diversity (presence of riffles, glides, and pools) has changed since 1939. This is about the time when placer mining began and when historic aerial photos first become available. An understanding of the long term trajectory of the channel's morphology, beginning with the impacts of placer mining, the 1964 flood, and then the elimination of cattle grazing in 1991, will provide a context for understanding the current habitat diversity and the extent to which the 1996 Summit Fire and subsequent flood event altered the channel trajectory and impacted habitat diversity. Additionally, the ongoing restoration projects both on the TNC reach and upstream of the property will benefit from this information.

Specifically, this thesis will attempt to answer the following list of temporally nested questions. The research questions address three time periods. The first period is from 1939 to 1991 when the main impacts to the channel were early Euro-American ranching and possibly the 1964 flood. This is also the time period prior to TNC ownership of the property. In order to isolate the impacts of the 1996 flood, the second time period is between 1991 (when the TNC acquired the property) and 1996. The last section looks at the post-flood channel from 1997-present. Questions 1 through 3 address each of these time periods respectively while question 4 considers the consequences of the results in terms of the ongoing restoration projects.

Research Questions

Question 1:

How has channel sinuosity changed since 1939 and to what extent has the channel laterally migrated since then?

Question 2:

What was the trajectory of channel change from 1991-1996? Specifically, how has the vegetation changed on the property since before and after TNC acquired the property and does this explain any of the changes in cross sections, sinuosity, bars, and habitat units?

Question 3: Effects of the 1996 flood and fire

(a) How has habitat diversity (presence/distribution of riffles, pools, and glides) on the Nature Conservancy's reach of the Middle Fork John Day changed between 1996 and 2008? How does the habitat diversity differ between the Nature Conservancy property and the Forest Service control reach that is just upstream where there is no cattle grazing?

(b) What, if any, impact did the 1997 flood have on the cross-sectional profile of the reach and did this change the trajectory that the channel was on following the grazing exclosure in 1991?

Question 4:

What are the sequence of events and dominant processes that have created the present day TNC reach morphology, and what are the implications of this for the present day restoration of salmon habitat on the property?

These temporally nested research questions examine the factors influencing channel morphology starting with the longer term effects of Euro-American settlement to the more recent TNC management, fire, and flooding. The degree to which past events shaped the channel is important for understanding the present day channel morphology and the extent to which more recent disturbances have altered the channel. Theories of channel morphology and disturbance suggest that the effects of disturbances should dampen out or reach equilibrium over time.

The first question looks at the impacts of Euro-American settlement when grazing, logging, and mining were the driving forces influencing channel morphology. Any changes that occur between 1991 and 1996 can be attributed to the change in land ownership and TNC management. Changes in trajectory occurring between 1996 and 2008 could be attributed to the effects of the fire, flooding, or restoration work that was started in 2004. In order to make statements about each time period it is necessary to look at the preceding channel conditions in order to determine how and if the channel has changed in response to significant events such as flooding, changes in land management, and restoration projects.

There is currently a large body of literature on the topic of river response to natural and anthropogenic disturbances. These papers generally focus on the effects of one particular type of disturbance such as grazing, fire, or dredging on the river system rather than looking at them all together. Results from these studies, however, provide a theoretical framework with which to understand the development of the present day channel environment of the Middle Fork and the possible effects that grazing, flooding, and fire have had. These disturbances influence the supply of sediment on the Middle Fork. The following literature review explores the influence of these processes on other rivers in order to better understand the possible impacts that similar events could have had on the Middle Fork channel morphology.

Channel Response to Flooding

In response to high flood discharges the most easily adjusted feature of a river is its cross-sectional profile, particularly its width (Knighton, 1998). High discharge events can mobilize sediment and widen a channel. If there is a sufficient supply of fine sediment following the flood event, flood-entrained sediment will be deposited as discharge drops, rebuilding the bars and banks that were previously eroded and removing evidence of the flood in channel form (Gupta and Fox, 1974). If flooding starts to occur with increased regularity, the flood form of the channel will be preserved (Gupta and Fox, 1974). Gravel channels require higher stages in order for bar erosion to occur because of armoring of the bed (Parker and Peterson, 1980 and Lisle, 1981). In the gravel channels of Lisle's (1981) study of gravel streams in northern California, bars are relatively stable and degrade slowly in response to long term trends in flow and sediment supply. The bed of the Middle Fork is covered in cobbles which could act to armor the bed reducing the impacts that disturbances have on the channel.

Lisle (1981) found that degradation tends to occur during periods without large floods, while aggradation is associated with large flood events when these channels are heavily influenced by debris flows and landslides. The recovery rate of a channel is also impacted by the growth rates of vegetation. Humid areas such as the Maryland Piedmont channels are more heavily stabilized by vegetation making them more resilient to flood events while more arid regions where vegetation grows slowly will be more easily altered and have slowed recovery rates (Knighton, 1998; Gupta and Fox, 1974). Fire and grazing have reduced bank vegetation on the Middle Fork which, according to previous work, may reduce the channel's resiliency to flooding. Additionally, Pitlick's (1993) study of a catastrophic flood in the Colorado Front Range suggests that the properties of the watershed including relief, vegetation, geology, and land use are as important as climate in controlling recovery because they are major factors influencing the supply of sediment. This highlights the importance of considering a variety of factors in addition to the obvious disturbances that could influence the morphology of the channel such as climate and geologic setting.

If the cross sections show no change in channel depth following the flood this could be due to bed armoring by large cobbles. Additionally, the reduction in bank vegetation from fire and grazing would destabilize banks, allowing an increase in discharge to cause a widening of the channel rather than increasing in depth.

Grazing

Grazing in the study area began in the 1880s when Euro-Americans settled the area and was discontinued when the Nature Conservancy acquired it in 1991 (Welcher, 1993). The impact of grazing on rivers has been explored in numerous articles which provide a context for understanding changes in the Middle Fork channel morphology following the end of grazing on the property with TNC ownership. The grazing of cattle has been shown to have significant impacts on the landscape both in the uplands and directly on streams, ponds, and riparian areas (Trimble and Mendel, 1995). Grazing in riparian areas destabilizes channels, decreasing the availability of effective fish habitat.

Upland grazing causes soil compaction, consequently increasing runoff and Hortonian overland flow. The overland flow then leads to increased erosion and can increase sedimentation in the stream. Reductions in vegetation most significantly increase erosion in areas that have sparse vegetation to begin with (Graf, 1979). Along the Middle Fork the valley alternates between wide and narrow stretches. These morphological differences in the valley form appear to have influenced land use and ownership along the Middle Fork, with cattle ranches dominating the wide sections and the narrow segments becoming Forest Service land (McDowell, 2001).

Cattle are attracted to streams especially in arid and semi-arid rangelands where the streams provide not only drinking water but possibly a better source of food (Trimble and Mendel, 1995). Grazing impacts stream channels through trampling and vegetation removal as cattle seek out streams for water and food. Trampling can cause banks to collapse and can remove stabilizing vegetation. Platts and Nelson (1983) found that grazing can reduce riparian vegetation by up to 80% which makes the channel more prone to erosion. Pools provide necessary resting areas and cover from predators for fish (Hunter, 1991). Disturbances along riparian areas have been shown to decrease important pool habitat and increase the presence of glides (McIntosh et al., 1994; Trimble and Mendel, 1995). In a study of channel adjustments to grazing exclosures on the Middle Fork John Day, Magilligan and McDowell (1997) found that ungrazed plots had a higher pool area and reduced low flow and bank full widths. This suggests that ungrazed areas will provide better habitat conditions for salmon.

Fire

As discussed above, changes to the amount of ground cover and soil properties of hillslopes have been shown to alter the runoff and erosions rates of hillslopes (DeBano et al*.,* 2004). The removal of ground cover through fire can exacerbate rates of erosion and runoff since ground cover aids in the infiltration of overland flow (Agee,1990; Wittenberg and Inbar, 2009). Both canopy and ground cover protect the soil from erosion by absorbing the direct impact of raindrops which would otherwise dislodge soil particles if they were to strike bare ground (Bryan, 2000; Johanson et al. 2001; Moody and Martin, 2001). Fire can also create water repellent soil surfaces which further increases runoff and erosion rates (Doerr et al, 2004). It has been shown that runoff and erosion rates are most heavily increased in the first year after a fire (Inbar et al, 1998; Fox et al, 2006; Wittenberg and Inbar, 2009). Disturbances such as fire, grazing, and logging can have some similar effects on a channel because they all result in the removal of vegetation. As discussed earlier, the removal of vegetation can increase runoff, erosion, and sedimentation into the stream, all of which decrease the availability of productive salmon habitat.

Since both fire and grazing have removed bank stabilizing vegetation there has likely been increased erosion along the channel. Also, since the channel bottom is armored with cobbles and boulders and bank-stabilizing vegetation is limited, this could result in a widening of the channel. Additionally, pool spacing may be reduced as disturbances along riparian areas in other studies have been shown to do (McIntosh et al., 1994; Trimble and Mendel, 1995).

CHAPTER II

STUDY AREA

The Middle Fork is one of three branches of the John Day River, which is a tributary of the Columbia River. The Middle Fork is approximately 121km long from its headwaters in the Blue Mountains to its confluence with the North Fork John Day. There are three dams on the Columbia River below the mouth of the John Day that anadromous fish must cross before reaching the study area on the Middle Fork. Salmon passage facilities at these lower dams allow some passage upstream. The focus of this study is the Nature Conservancy's Dunstan Preserve and the U. S. Forest Service (USFS) property located adjacent to and upstream of the preserve (Figure 1). This study area was selected because there are currently several ongoing river restoration projects whose goals are to increase and improve habitat for salmon and other wildlife by mitigating the impacts of the area's long history of human disturbance. Additionally, no formal analysis had been done of the data that TNC has been collecting since 1991.

The TNC Dunstan Preserve is 1,199 acres in size (Figure 1) and is located between mile markers 13-17 along County Route 20 northwest of the town of Austin. The property was homesteaded in 1888 and acquired by the TNC in 1990 (The Nature Conservancy, 2009). The total length of channel in the study area is about 10.5 river km. This length is divided into two reaches, the Dunstan reach comprising 8.2 river km starting at approximately river mile 50 and the Forest Service reach comprising 2.3 river km starting at the upstream boundary of the Dunstan reach. The study area is located about 32km from the headwaters of the Middle Fork.

The Middle Fork basin, which is located in the Blue Mountains, is predominantly forested with Ponderosa pine and Douglas fir taking up two thirds and range and pasture land the remaining third of the land. The majority of the Middle Fork basin is managed by the US Forest Service (Malheur National Forest and Umatilla National Forest) with a small portion managed by the BLM and only about 2% privately owned (Malheur NF, 2008; Welcher, 1993). Three main tributaries enter the Middle Fork at the Dunstan Preserve: Big Boulder Creek, Coyote Creek, and Horse Creek (Figure 1).

Climate data are recorded at the weather station in Austin approximately 19km to the southeast of the Dunstan Preserve. The data are publicly available from the National Oceanic and Atmospheric Administration (NOAA.gov) and summaries of the data are available from The Western Regional Climate Center (WRCC, 2009). Climate records have been kept at the station since 1948. The average annual air temperature is 5.3 ^{o}C (41.6^{o}F). Winter (*Dec-Feb*) temperatures average -4^{o}C (24.8^{o}F), spring (*Mar-May)* 4.6 ^{o}C (40.3^{o}F), summer (*Jun-Aug*) 14.9 ^{o}C (58.9^{o}F), and fall averages (*Sep-Nov*) 5.8 ^{o}C (42.4^{o}F).

Austin receives an average of 52.2cm (20.57in) of precipitation a year with the majority of it in the fall and winter months. Mean annual snowfall is 220.8cm (86.8in). Discharge is measured 65km downstream of the study site at the Ritter gauging station. Peak discharges are seen in the winter and spring as a result of snowmelt and high rain runoff while low flows are typically in August and September. For the period of record (1927-present) the highest peak discharge was 4360cfs on January 30, 1965 (Figure 3). The second and third highest peak discharges occurred on January 1 and 2, 1997 in the winter following the Summit Fire. The discharges were 3930cfs and 3440cfs respectively (USGS water data, 2009).

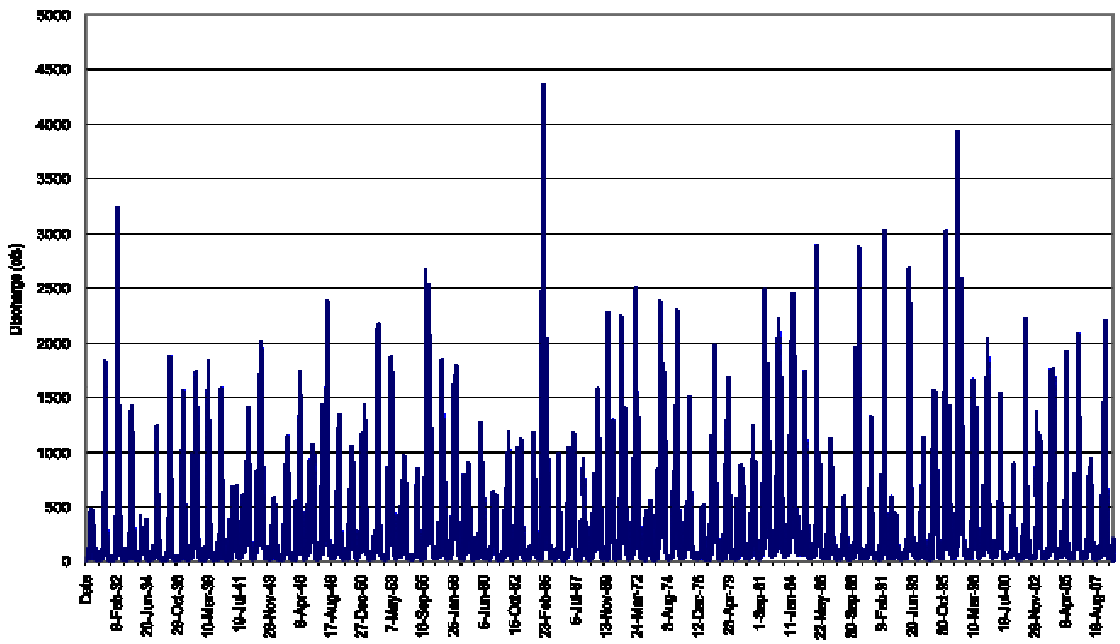


Figure 3: Peak daily discharge at the Ritter gauging station downstream of the study area.

Geology and Sediment Sources

In the study area the Middle Fork valley runs through the 37-54 million year old Clarno Formation. The sedimentary rocks in the Clarno Formation were deposited as a result of debris flows and fluvial processes (Bestland, and Retallack, 1994). Additionally, lahar deposits can also be found in the Clarno Formation. The Middle Fork valley floor contains Quaternary alluvium containing andesite, basalt, granite, and sedimentary rocks (Walter and MacLeod, 1991 and Welcher, 1993). The valley contains deposits from glacial outwash, mass wasting, debris flows, and overbank flood deposits of the surrounding slopes (Welcher, 1993).

Sediment that enters the Middle Fork channel comes from the surrounding hill slopes and erosion of the channel. Differences in the Middle Fork's channel morphology over time can likely be attributed to factors that alter the sediment supply such as changes in land use, restoration projects, fire, and grazing practices. While cattle have been eliminated from the TNC property they continue to be allowed to graze the property upstream of the preserve while deer and elk can graze freely on all portions of the river. Examples of the impact of deer and elk grazing can be seen upstream on the Oxbow properties where planted trees are stunted from the grazing of wildlife.

River Channel and Floodplain Morphology

The Middle Fork has many factors influencing its present form. Dominant factors influencing channel form on the Middle Fork are valley width and human impacts (McDowell 2001). McDowell (2001) also found that the channel is more sinuous in areas where the valley is wider. However, these meanders have been influenced by human impacts. The wide valleys along the Middle Fork have greater sinuosity, more pool area, and deeper pools than the valleys, while wide valleys where dredge mining and grazing occurred tend to look more like the narrow valleys (McDowell, 2001). Meander scars and relict cutoff channels on the floodplain suggest that it once had both meandering and anastomosing reaches. Scars of old side channels and meander scars can be seen on aerial photos. The channel bed is mostly made up of coarse gravel and cobbles which armor the channel bed. Large boulders that have fallen from the surrounding slopes are also present in the stream. Three geomorphic surfaces have been identified in the study area: alluvial fans and two different terraces. There are three alluvial fans on the north side of the channel that extend out of Horse Creek, Coyote Creek, and Big Boulder Creek. The alluvial fan of Big Boulder Creek appears to push the channel against the south valley wall, narrowing the floodplain in this area (Figure 4).

Disturbance History

A timeline summarizing the history of disturbances can be seen in Figure 2. Gold miners first settled the Middle Fork John Day valley starting in the 1860s, mostly focusing their mining efforts on the tributaries and conducting placer mining by hand. By 1933 and continuing through the early 1940s the Middle Fork was dredged for gold about 10.4km upstream of the study area (Welcher, 1993). Legacies of the dredge mining such as tailings piles and the characteristic zigzag patterns left by the dredge on the floodplain can be seen on the 1946 aerial photos. The dredging upstream of the Dunstan Preserve is believed to have released a large amount of fine to cobble size sediment which exceeded the carrying capacity of the channel (Welcher, 1993). This would have had a significant impact on the morphology of both the Forest Service control reach and the Dunstan Preserve reach downstream. Also, due to of mining operations, water was diverted along a 19.2km ditch extending from Big Boulder Creek to the town of Susanville to the west (Welcher, 1993).

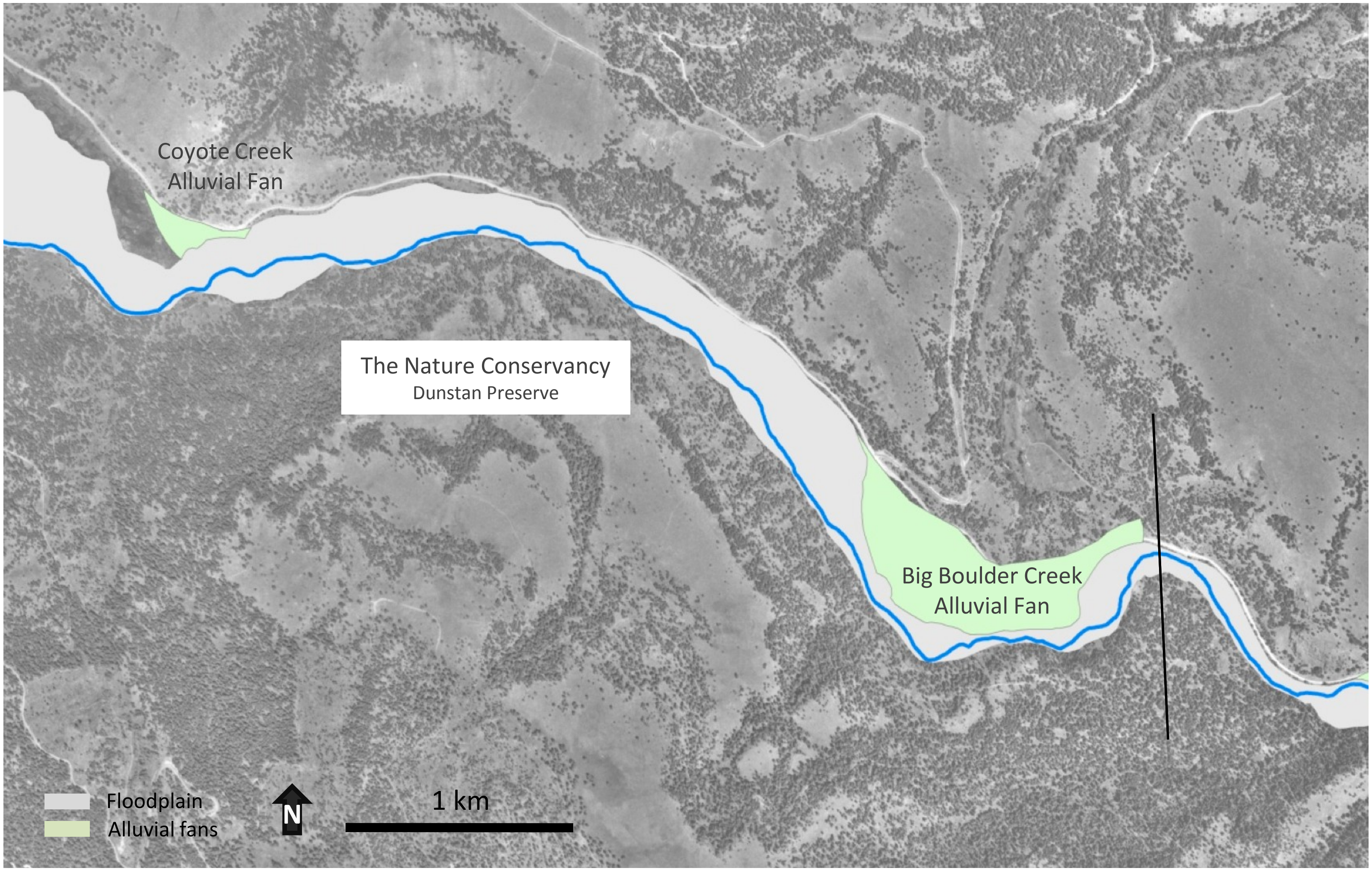


Figure 4: This figure shows the alluvial fan boundaries on the flood plain for Big Boulder Creek and Coyote creek. At these two locations the fans are pushing the channel over to the south side of the valley where they are contained by the steep slopes.

Other forms of resource extraction such as logging continue to take place in the Middle Fork basin. In the 1940s logs were dragged down the tributaries leaving scours in the channels (Grant, 1993; Welcher, 1993). Additionally, logging can destabilize the soil, increasing the amount of fine sediment in the stream. Grant (1993) found that open spaces on the floodplain can be attributed to both natural causes and logging by settlers in order to create meadows of hay. On the Middle Fork, logging and mining created the need for a railroad that was constructed sometime between 1910 and 1920 (Clair and Fields, 2004; Welcher, 1993). The main railroad was constructed through the valley with spurs running out from it including one up Big Boulder Creek (Figure 5). River meanders were first cutoff by the Sumpter Valley Railroad in the early 1900s. Evidence of the railroad grade can be seen as 1.5m rises in the floodplain. It is believed that the railroad grade has limited the ability of the Middle Fork to meander naturally for about two kilometers downstream of Big Boulder Creek (see Figure 5; Welcher, 1993). When the Dunstan Family homesteaded the property in 1888 they began managing the area for agriculture which continued up until the TNC acquired the property in 1991. The last major channelization was carried out by the landowners in the 1970s. Channelization on the Dunstan Property pushed the river towards the south valley wall causing secondary channels to be cut off from the mainstem (Clair and Fields, 2004).

Prior to Euro-American settlement in the valley, the native forest was predominantly ponderosa pine (*Pinus ponderosa*) with a fire regime of low severity fires and 10-35 year recurrence intervals (Agee, 1996; McIver and Ottmar, 2006). As a result of fire suppression Grand fir and Douglas fir trees are becoming more common. Also, because of the fuel build up along the forest floor and logging practices, the fire regime has been altered from one of frequent low-severity fire to infrequent high-severity fires (McIver and Ottmar, 2006).

Several large fires have burned along the slopes of the study area in recent years including the 1984 Indian Rock Fire (1,410 acres), and the 1994 Reed Fire (2,338 acres) (Figure 6). The largest fire, the 1996 Summit Fire, burned 37,986 acres (Malheur National Forest, 2008). The Summit Fire was determined to have burned at a high severity, which is defined as having at least 80% large tree mortality (USDA, 1997). The fire burned down into the valley and jumped the channel at the Dunstan Preserve near the mouth of Big Boulder Creek. Big Boulder Creek and its tributaries run through the Summit Fire boundary (Figure 6). The Summit Fire occurred during the summer of 1996. This was followed by a large flood event during the winter of 1997. Running through the burned area, Big Boulder Creek provides a means for channeling the eroded sediment into the Middle Fork at the upstream end of the TNC property. Erosion and deposition of sediment were observed using aerial photos. The cobble bar at the downstream side of the confluence could also be observed in the summer of 2008 while conducting fieldwork. Morphological impacts of the 1997 flooding down Big Boulder Creek will be discussed later in the results and conclusions portion of this thesis.

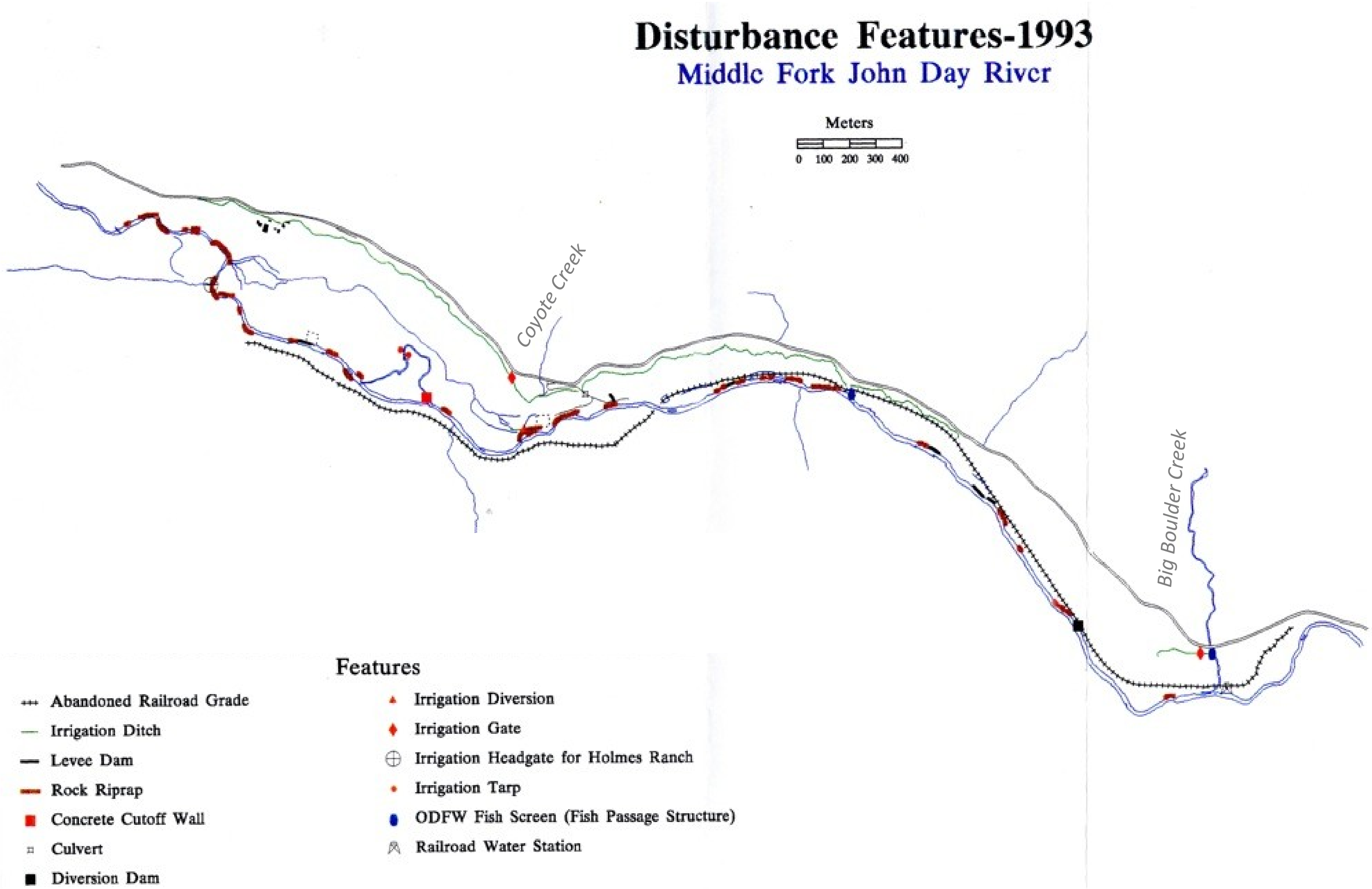


Figure 5: Disturbance features mapped by Welcher (1993).

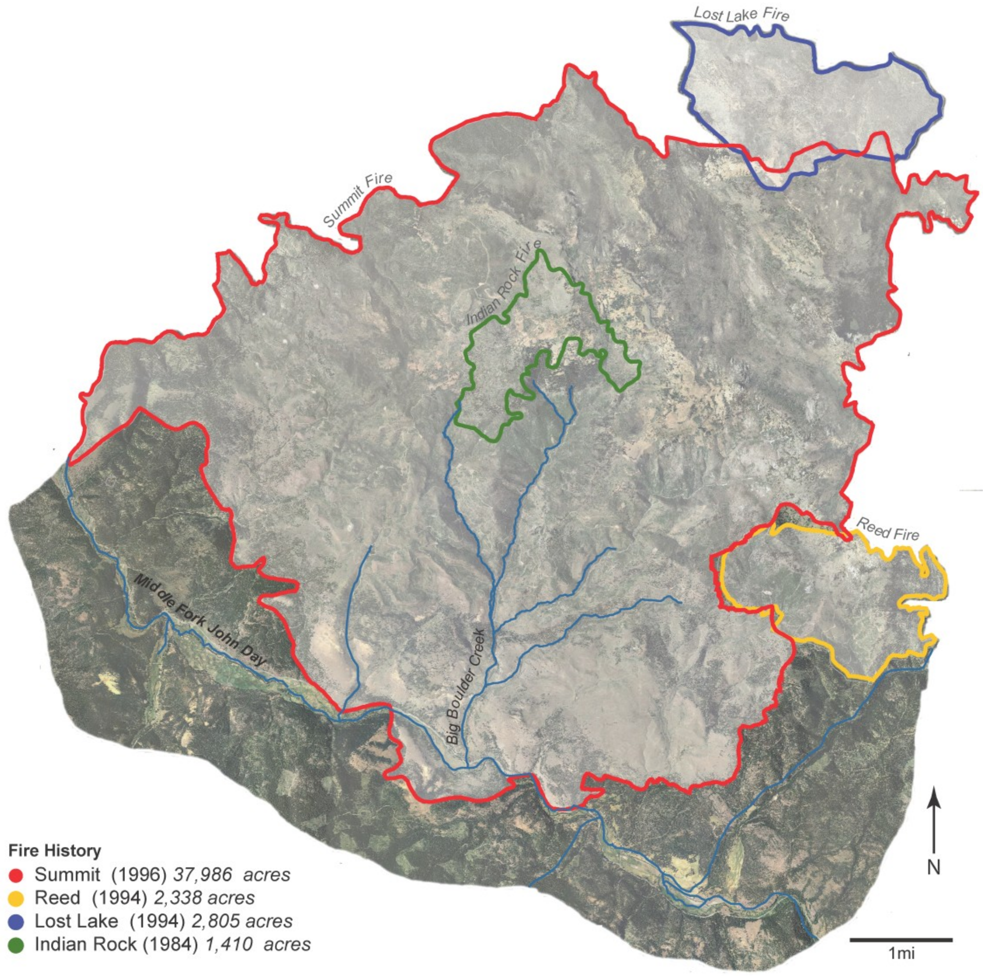


Figure 6: Large fire history surrounding the TNC property. The high severity Summit Fire outlined in red, burned 37,986 acres in the summer of 1996. The river flows right to left.

CHAPTER III

METHODS

Since acquiring the property in 1991 the TNC has been collecting both ecological and geomorphic data but no formal analysis of these data has been done (TNC, 2009). These TNC data as well as habitat data from the Forest Service provide an opportunity to analyze recent changes in channel morphology in the context of the historical impacts of grazing and dredge mining. The following chapter outlines the sources of data and methods used to analyze them.

Data Sources

Maps of past field work and field notes of study sites from 2005 taken by The Nature Conservancy were used to verify the locations of the permanent cross sections and to determine which ones could be re-surveyed in 2008. Re-survey was based on whether or not the marked rebar could be found. Cross section data for the TNC reach are available for 1991, 1996, 1997, 2005, and 2008. The TNC collected data in 1991, 1995, and 2005. Patricia McDowell, University of Oregon, collected and provided the 1997 data for this study. The cross sections were measured at the same sites during the five sample years. During the summer of 2008, I surveyed a more recent set of cross sections for the study area. Habitat unit surveys are available for 1996 and 2008. The 1996 data are from the summer before the 1997 flood. The 1996 data were produced by the Oregon Department of Fish and Wildlife and the 2008 data are from the U.S. Forest Service. The same methods were used for sampling the data, but there were some differences in data labeling. For example pools, riffles, and glides were labeled slow, turbulent, and fast, respectively, in the USFS data while the ODFW data were given numeric values to designate unit type.

Aerial photos were obtained from the University of Oregon MAP Library. Aerial photos are available at about decadal intervals (1939, 1946, 1956, 1965, 1984, 2005, and 2008). The LIDAR was flown during the summer of 2008 and has been used to determine the slope of the study reaches. Finally, discharge data are available since 1920 from the nearest USGS gauging station 65km downstream at Ritter. The methods used to obtain and analyze these data are described below.

Control Site Selection

In order to effectively monitor the impact of a particular disturbance Downes et al. (2002) call for the selection of a control site free from the effects of the disturbance being studied. Additionally, an effective control site should be located upstream of the disturbance since the flow of water transports the effects of the disturbance downstream. For these reasons the U. S. Forest Service reach which is directly upstream from the TNC reach and Big Boulder Creek was selected as a control. Unlike the TNC reach, the Forest Service reach lacks a grazing exclosure and continues to be grazed. It is also located upstream of the Big Boulder Creek confluence, so the impacts of the flooding down Big Boulder Creek after the 1997 flood would not likely be evident there. Habitat surveys and aerial photographs are available for the same years for both reaches. The habitat data and aerial photos allow for a comparison of the presences of pools, riffles, and glides, changes in the floodplain vegetation, channel width, lateral migration, and sinuosity between the two reaches.

Downes et al (2002) also discuss the temporal scales that disturbances can occur at and the need to select an appropriate monitoring time frame based on the type of disturbance. In this study I wanted to focus on the effects of the impacts of the TNC's management of the property as well as the effects of the 1997 flood. To understand the changes to the channel during this time it was necessary to determine the condition of the channel prior to TNC ownership. Since the area has a history of human disturbances dating back to the early 1900's it was important to capture as much of those impacts in this study as possible. With aerial photos of the area first available in 1939, just before dredging began upstream, this was a convenient time frame for this study. The aerial photos provide data for observing the impacts of the many types of disturbance that have occurred during the last 80 years. These photos provide snapshots of the channel at decadal intervals. This helps provide a context for the changes in the channel that are observed in the more detailed data over the last 20 years.

Fieldwork

The fieldwork for this project was completed in August 2008. The cross sections were used to determine how channel morphology has changed since the TNC acquired the property and to determine what impacts if any the 1997 flood had on the channel. Cross-sections were re-surveyed if the right and left rebar could be relocated in the field. The cross sections were measured using an auto level and a stadia rod, following the methods of Harrelson et al. (1994). A measuring tape was stretched across the channel and secured with a stake at the rebar on either side of the bank. Depths were measured at 0.5m intervals and at significant features along the channel such as the base of a cut bank if it did not fall on a 0.5m interval. Records were kept in a field notebook of elevation recorded on the rebar, distance along tape, stadia rod reading, and a description of the data point (i.e. floodplain, channel edge, presence of aquatic vegetation, gravel bar, etc.). Additionally, photos were taken to show upstream, downstream, and the left and right banks of each cross section. The photo numbers were recorded in the field notebook with descriptions.

Cross Section Data Analysis

The Nature Conservancy data were first converted to metric units then plotted in Microsoft Excel alongside the 1997 data from Patricia McDowell and the 2008 data I measured. Bank full width to depth ratios were calculated for each cross section. The differences between the values for each successive year were calculated for each cross section site in order to describe the changes in the channel profile over time. Cross sections were also plotted on top of each other in order to visually identify changes over time. Knowing how the channel has changed between each of the years shows the trajectory of the channel change and can be used to answer questions on channel response after the 1997 flood and different grazing management practices over time.

Habitat Unit Surveys

The habitat unit surveys cover a larger extent than the cross sections which only cover part of the TNC reach. Because the surveys cover both the TNC and the USFS reaches they can be used to compare habitat diversity between the two properties to show how the different management practices on the two properties have influenced channel morphology. The number and location of large woody debris were also mapped along the stream channel.

The 1996 ODFW habitat surveys were downloaded as shapefiles from the ODFW Aquatic Inventory web site. They were already dynamically segmented, so they simply needed to be opened in ArcMap to be analyzed. The 2008 USFS habitat surveys were received as an Excel workbook which was then used to dynamically segment the stream center line in order to display the individual habitat units in GIS. Methods for dynamic segmentation can be found in Appendix 1. Once both surveys were opened and the habitat units symbolized in GIS, changes to the distribution and size of pools, riffles, and glides could be measured. Statistical analysis of the habitat data was done in Excel.

The data were divided into two groups: downstream of Big Boulder Creek compared to upstream of Big Boulder Creek, and the Nature Conservancy property compared to the USFS property. Big Boulder Creek is used as a dividing point in order to determine its influence on the Middle Fork channel morphology following the 1997 flood because this tributary runs through the burn and sediment deposition was observed at its confluence with the Middle Fork. The upstream portion of Big Boulder Creek did not have the same sediment input from the fire and flood. Upstream of Big Boulder Creek includes both TNC and USFS property while the downstream portion is just TNC property (Figure 1).

The data are also divided by TNC and USFS in order to answer questions on management differences between the two properties their effects on the channel. Statistical comparisons using a T-test were made between these categories for habitat unit length, habitat unit area, total number units per km, channel width, average channel depth, pool depth, riffle depth, width to depth ratio, and number of large woody debris per km. Averages for the habitat units (i.e. average width, depth, etc) were calculated by averaging the measurements from the habitat unit data table and weighting them based on habitat unit length.

Aerial Photos

Historical aerial images of the study area are available for 1939, 1946, 1956, 1965, 1984, 2005 and 2008. Contact prints of photos from 1939 through 1984 were scanned, georectified and digitized using the methods recommended by Hughes et al. (2006). For each of the years a channel centerline was digitized in order to analyze channel migration and changes in sinuosity over time. Channel centerline was defined by drawing a line feature down the middle of the channel (estimated by eye) on the aerial photos zoomed in at a scale of 1:3000. The aerial images were also used as a base layer to display the habitat data in GIS. This helps provide the spatial context for the habitat data in order to observe changes in habitat relative to important features on the landscape such as tributaries and property boundaries. Additionally, the photos were used to examine changes over time in floodplain and bank vegetation in order to infer the causes of the changes channel and habitat units.

CHAPTER IV

RESULTS

Sinuosity and Channel Migration

Sinuosity on the TNC reach was 1.29 in 1939 (Table 1). The next measurement was taken in 1956 and by then the sinuosity had decreased to 1.25. From 1956 to 2006 the sinuosity of the reach remained between 1.24 and 1.25 (Table 1). The difference in sinuosity after 1939 is apparent in Figure 7. On the west side of the map, the 1939 channel had two large meanders in the floodplain. After 1939, the channel was pushed to the south valley wall and remained relatively unchanged for the next 60 years. While the scar from these two meanders can still be seen on the floodplain, water no longer enters this channel.

Table 1: Channel sinuosity for The Nature Conservance (TNC), Forest Service (USFS), and overall study area (Total).

	Sinuosity		
	TNC	**USFS**	**TOTAL**
1939	1.29	1.31	1.30
1956	1.25	1.30	1.26
1976	1.25	1.32	1.27
1984	1.24	1.31	1.26
2000	1.25	1.33	1.27
2006	1.24	1.32	1.27

The USFS reach had a sinuosity of 1.31 in 1939 and showed little change during the study period. From 1939 to 2006, sinuosity ranged between 1.30 and 1.33 (Table 1). Although the overall sinuosity of the study area was highest in 1939, the highest sinuosity in the USFS reach occurred in 2000. Similar to the TNC reach, the USFS channel was pushed to one side of the valley and remained there over the course of the study period with very little change (Figure 7). The floodplain is wider on the eastern edge of the map and this is where the channel showed the most change. The 1939 and 1956 channels occupied the north side of the floodplain. By 1976 one section of the channel migrated to the south side of the floodplain and remained there through 2006 (Figure 7). Despite having a narrower floodplain than the TNC reach, the USFS reach was significantly more sinuous throughout all survey years. The sinuosity of the two study reaches combined was 1.30 in 1939 and decreased to 1.26 by 1956 (Table 1). This change is attributable to loss of sinuosity in the TNC reach. For the remaining years, sinuosity remained at 1.26 to 1.27. The channel centerlines shown in Figure 7 show very little change in the overall location of the channel.

Habitat Surveys

The 1996 habitat survey (Figures 8 and 9) showed a channel environment dominated by long riffles, with a few short pools, and even fewer glides scattered in between. There were a total of 21 pools in the study area, with 12 on the TNC reach and 9 on the USFS reach. The spacing of units on the TNC and USFS reaches was similar, however three of the pools on the TNC were significantly longer than the USFS pools (Figures 8 and 9). The similarity between the TNC and USFS reaches in 1996 is highlighted in Table 2 which shows the percent of the total length in each unit. Riffles dominate the study area comprising 75.5% of the TNC reach and 73% of the USFS reach. In contrast, pools only make up 19% and 16% of the length of the TNC and USFS reaches respectively.

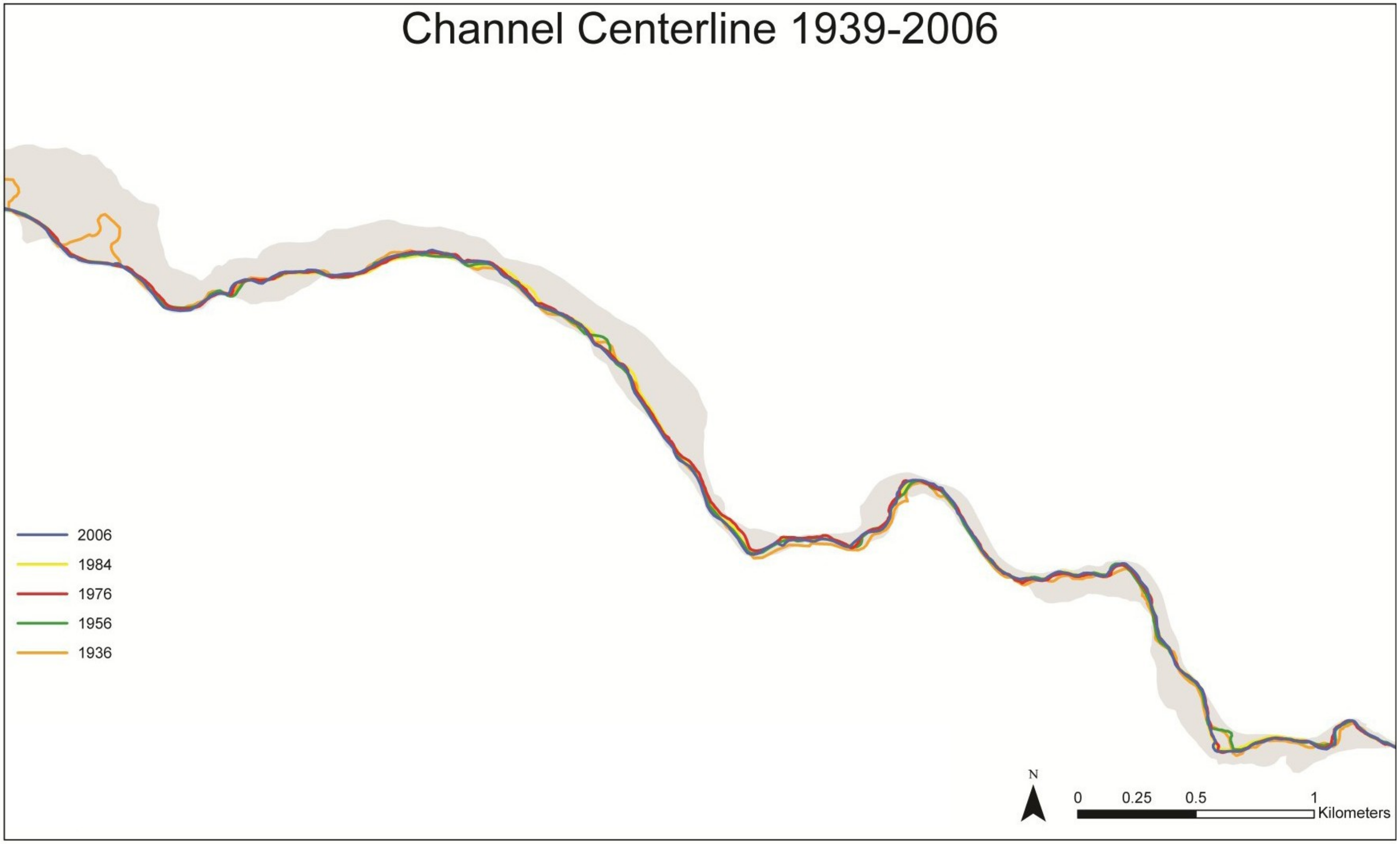


Figure 7: Map of channel centerlines 1939-2006

By 2008 the channel showed some significant changes (Figures 8 and 9). On the TNC reach, the riffles became much shorter because of an increase in pools. The pools were interspersed between what used to be long continuous riffle units. Between 1996 and 2008 the number of pools more than doubled on the TNC reach, increasing from 12 to 25. These pools are listed as being under large woody debris structures or as backwater pools created from woody debris. Additionally, the survey notes describe restoration work going on in the channel around the pools. Many or all of the new pools may have been directly constructed as part of the restoration work. The Big Boulder Creek confluence was a large pool in 1996. By 2008 it was a riffle unit. The USFS reach showed almost no change between the two surveys (Figure 9, Table 2). The 2008 channel had a decrease in the number of pools from 9 to 8. On both the TNC and USFS reaches the pools migrated short distances downstream from their 1996 locations.

Differences between the TNC and USFS reaches in 2008 are shown in Table 2 and 3. The Nature Conservancy reach is 5,013m long and the Forest Service reach is 2,360m. Since they are different lengths, habitat diversity is expressed as number of habitat units (pools, riffles, and glides) per km (Table 3). These data support the observations made from Figures 8 and 9 and the results in Table 2 in the previous paragraphs. In 2008 habitat diversity (units/km) is slightly higher on the TNC reach. Specifically, the number of riffles per km is highest on the TNC while the USFS reach has more glides per km. In 2008, the TNC had a habitat diversity higher than that of the USFS reach (Table 3).

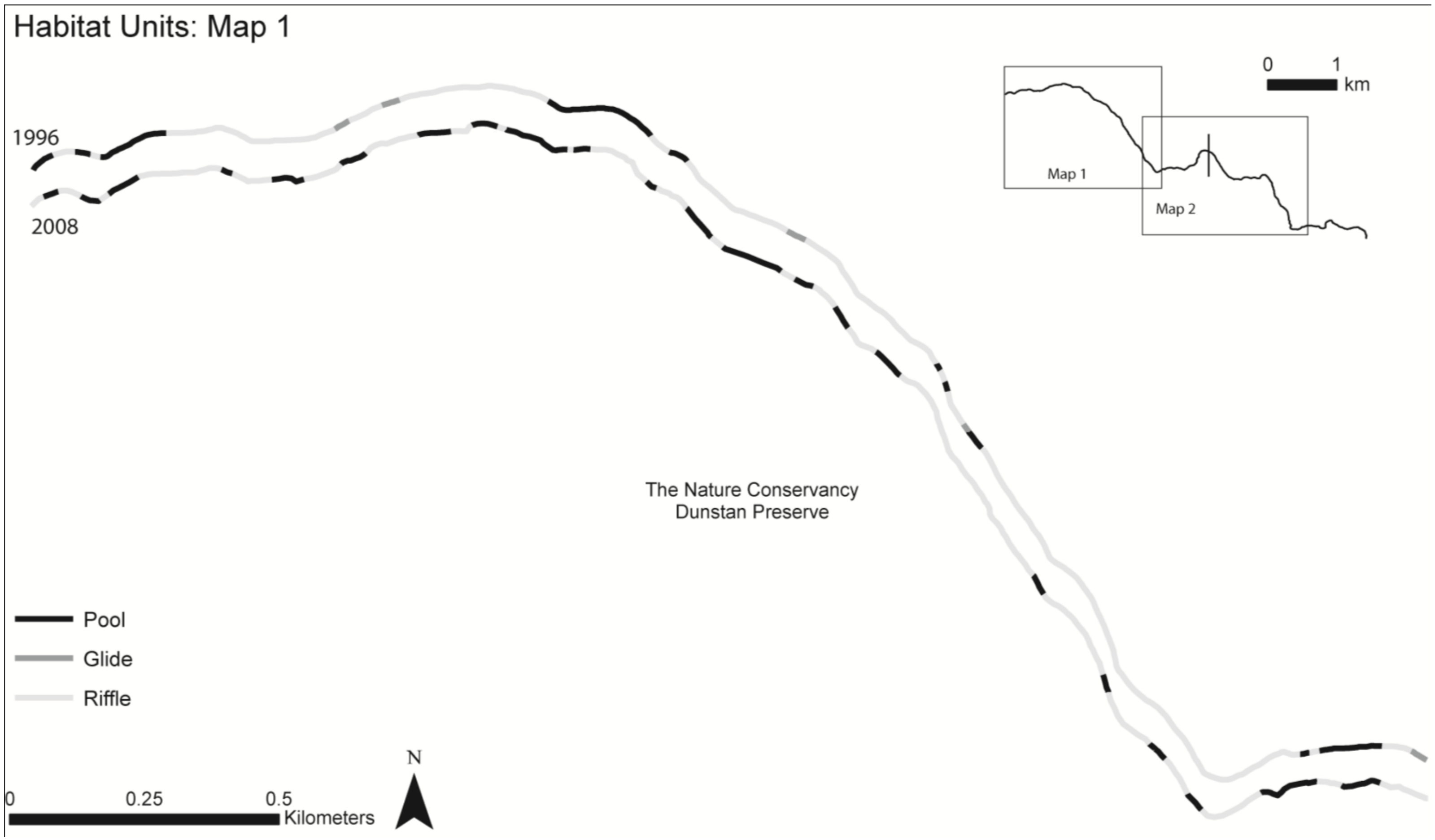


Figure 8: Map 1 of channel units in 1996 and 2998 in the downstream portion of the study area.

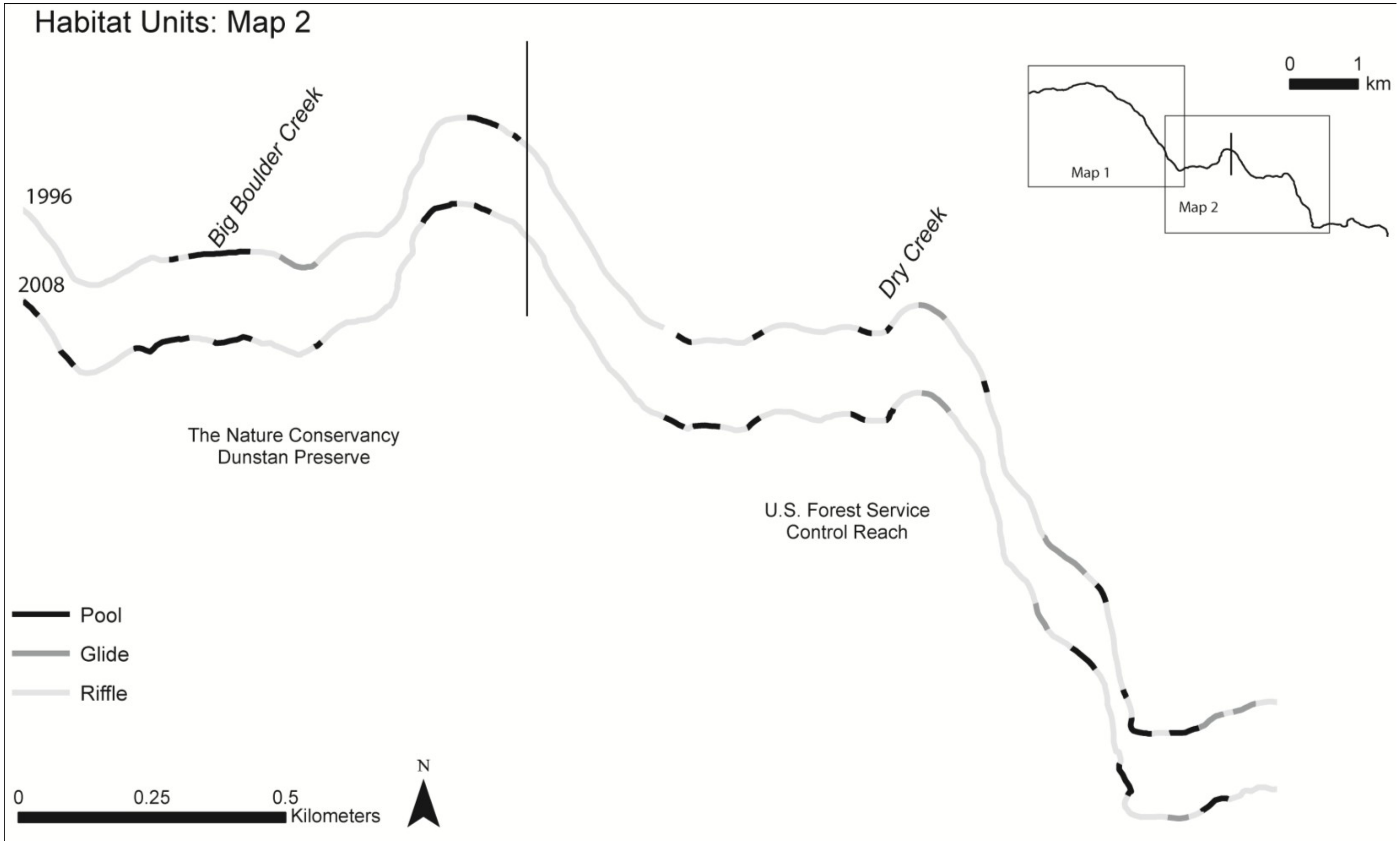


Figure 9: Map 2 of channel units in 1996 and 2008 in the upstream portion of the study area.

Table 2: Percent of the total length in pools, riffles, and glides.

1996			
	TNC	USFS	Total
% Pool	19	16	17.5
% Riffle	75.5	73	75
% Glide	5.5	11	7.5
2008			
	TNC	USFS	Total
% Pool	36	19	31
% Riffle	63	75	66
% Glide	1	6	3

Table 3: Habitat unit summaries for The Nature Conservancy and Forest Service study reaches. Upstream refers to the reaches upstream of Big Boulder Creek. This includes a small portion of TNC reach and all of the USFS reach. Downstream refers to downstream of Big Boulder Creek and is all TNC property.

2008									
TNC					**Downstream**				
	Riffle	Pool	Glide	Total		Riffle	Pool	Glide	Total
Count	56	55	1	112	Count	43	50	1	94
Avg. Max Depth(m)	0.5	0.8	0.6	-	Avg. Max Depth(m)	0.6	0.9	0.6	-
Avg. Width (m)	10.0	11.5	8.2	11.2	Avg. Width (m)	11.4	9.8	8.2	10.8
Width:Depth	20.9	13.0	8.2	-	Width:Depth	20.3	12.4	8.2	-
HabUnits/km	8.51	8.36	0.15	17.02	HabUnits/km	7.45	8.67	0.17	16.29
USFS					**Upstream**				
	Riffle	Pool	Glide	Total		Riffle	Pool	Glide	Total
Count	26	25	6	57	Count	39	30	6	75
Avg. Max Depth	0.6	0.7	0.6	-	Avg. Max Depth	0.55	0.84	0.59	-
Avg. Width	12.69	11.38	13.87	11.88	Avg. Width	12.47	11.30	12.29	12.09
Width:Depth	23.53	13.53	15.71	-	Width:Depth	23.34	14.26	21.35	-
HabUnits/km	6.57	6.32	1.52	14.41	HabUnits/km	8.18	6.29	1.26	15.73

Habitat diversity up and downstream of Big Boulder Creek was examined to detect impacts of the fire and increased sediment inputs. Habitat diversity is only slightly higher downstream of Big Boulder Creek with a difference of 0.57 units/km. The percentages of pools and riffles by count is very similar upstream and downstream of the confluence (Table 3). Glides are more frequent upstream than downstream .

Other differences in channel morphology recorded in the habitat survey were examined for the TNC vs. USFS reaches, and the upstream of Big Boulder vs. downstream reaches. In terms of width to depth ratio of pools, the TNC and USFS reaches are not significantly different (Table 4). The width to depth ratio of riffles is lower for the TNC compared to the USFS property. The difference in pool depth between the TNC and USFS property is not significant. Average depth of riffles on both the TNC and USFS reaches is also the same. The TNC is on average narrower than the USFS. Despite the overall channel width being wider on the USFS reach, pool width was slightly higher on the TNC (Table 2), but this difference is not significant.

The width to depth ratio of pools is greater downstream of Big Boulder Creek than upstream (statistically different at 90% confidence interval; Table 3). Width to depth for riffles is the same downstream and upstream of Big Boulder Creek (Table 3). Pools downstream of Big Boulder Creek average a depth of 0.89m which is not significantly different compared to 0.85m deep upstream of the confluence. Upstream of the confluence, the channel is wider compared to downstream of Big Boulder Creek (statistically significant at the 95% confidence limit; Table 3). When broken down into the different habitat unit types it is consistently wider upstream than downstream of Big Boulder Creek.

Table 4: Results of T-Test for 2008 habitat data. * denotes significantly different at 95% confidence between USFS and the TNC reach and then upstream and downstream of Big Boulder creek.

	2008						
	W:D Pools	W:D Riffles	Avg. Depth	Width	Length	Pool Depth	Riffle Depth
Downstream vs Upstream	0.10	0.10	0.25	0.01*	0.60	0.36	0.18
TNC vs USFS	0.62	0.10	0.26	0.08	0.18	0.17	0.49

Large Woody Debris

Between 1996 and 2008, there was a significant decrease in the amount large wood present in the study area (Figure 10). In 1996, there was an average of 18.3 pieces/km and in 2008 there were 13.1 pieces/km. There is slightly more wood upstream of Big Boulder Creek than downstream in both years, but overall the amount of wood both up and downstream decreased in 2008. The TNC reach however, had a significant increase in large wood by 2008 (Figure 10). The majority of the increase in wood on the TNC reach occurred in the section of river from Big Boulder Creek upstream to the USFS property boundary. This increase is probably due to large wood pieces added during the restoration project. The greatest decrease occurred on the USFS reach which went from 14.6 pieces/km down to 0.9 pieces/km (Figure 10).

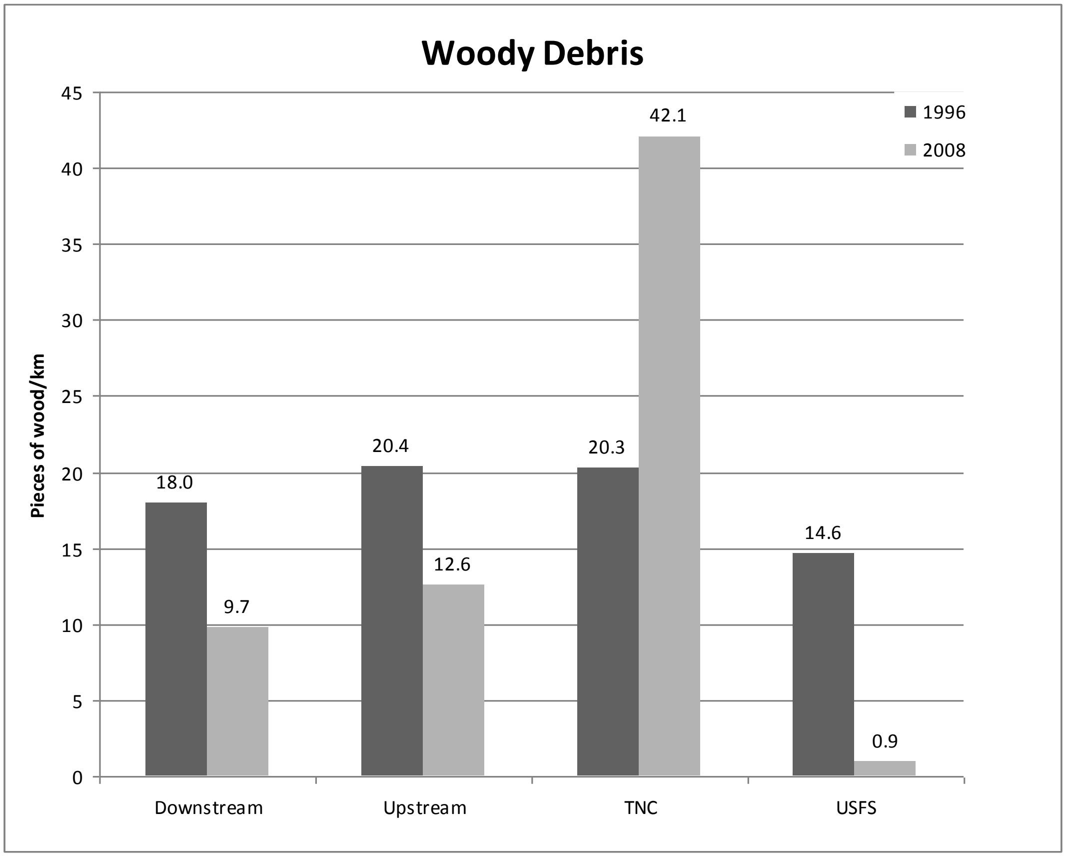


Figure 10: Large woody debris expressed as pieces of wood per km. The 2008 counts include wood from the constructed structures on the TNC.

Cross Sectional Profiles

The locations of the seven cross sections can be seen in Figure 11. Two of the sites are downstream of the Big Boulder Creek confluence and four are upstream. Between 1991 and 1996 very little change occurred for most of the cross sections sites. The greatest change in channel form occurred between 1996 and 2005. The following paragraphs describe changes in the cross sectional profiles starting downstream with R5Run1and finishing with the cross section farthest upstream, R3Rif4.

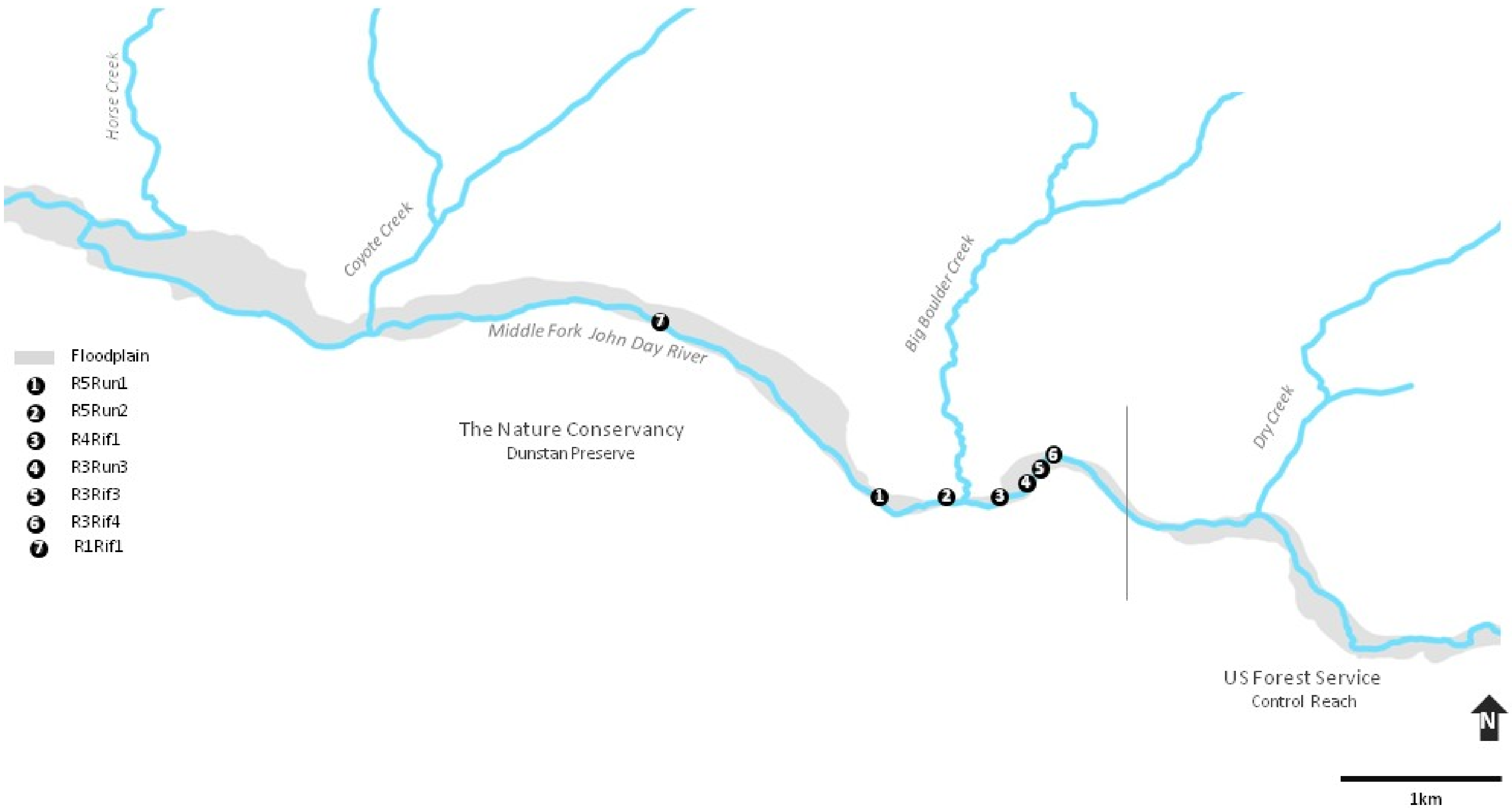


Figure 11: Location of cross section sites used in this thesis

Cross section R5Run1 (Figures 11 and 12) was categorized as a glide when it was initially surveyed in 1991. The 2008 cross section was shorter because the rebar had been washed out and was replaced closer to the channel. Between 1991 and the next survey in 1996, the channel deepened very slightly while the overall shape of the channel remained nearly the same. The greatest changes occurred after 1996 with incision of about 1m. Much of this incision occurred between 1996 and 2005, but the 2008 survey showed continued incision on the left and right of a new mid-channel bar. The right bank agraded consistently over the course of the survey period from 1991-2008, but total bank growth was only about 1 m.

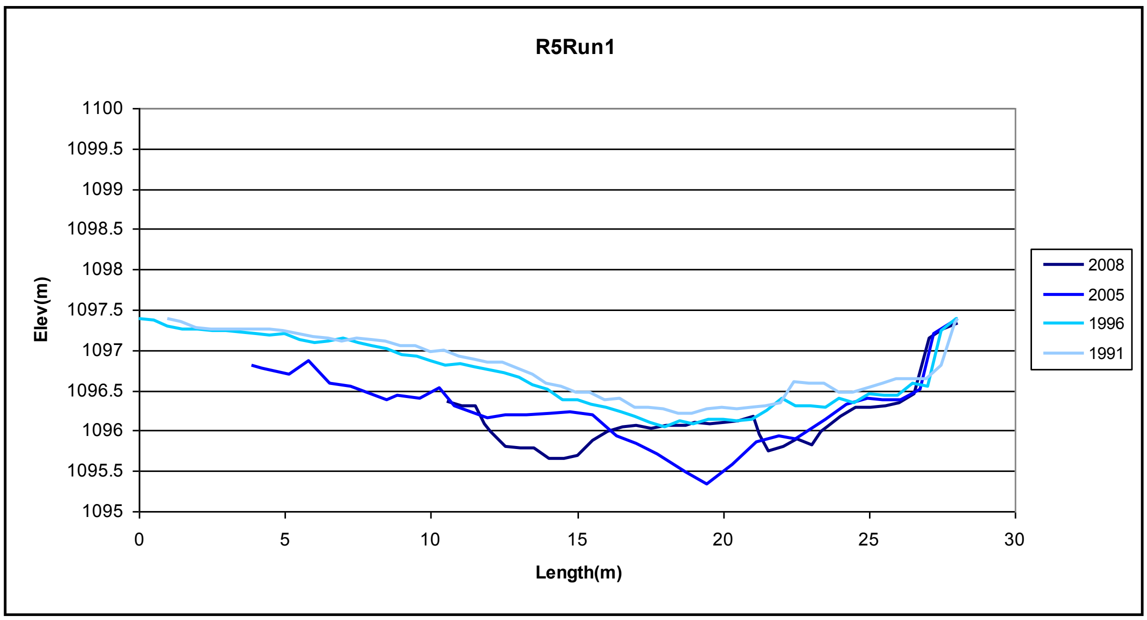


Figure 12: Cross sectional profile of R5Run1 downstream of Big Boulder Creek

Moving upstream to cross section R5Run2 (Figures 11 and 13), there was a similar trend to the previous cross sectional profile. Between 1991 and 1996 the thalweg remained in nearly the same place and there was slight aggradation just to the right of the thalweg. From 1996 to 2005, the thalweg shifted farther to the left side where it got almost 1m deeper. There was little change in the thalweg between 2005 and 2008. The bar on the right bank fluctuated over the course of the study period, alternating between periods of aggradation and degradation. Between 1996 and 2005, the bar aggraded and after 2005 it started to incise again. Incision of the thalweg was the dominant trend for this cross section over the course of the four survey years. The greatest rate change in the profile occurred between 1996 and 2005.

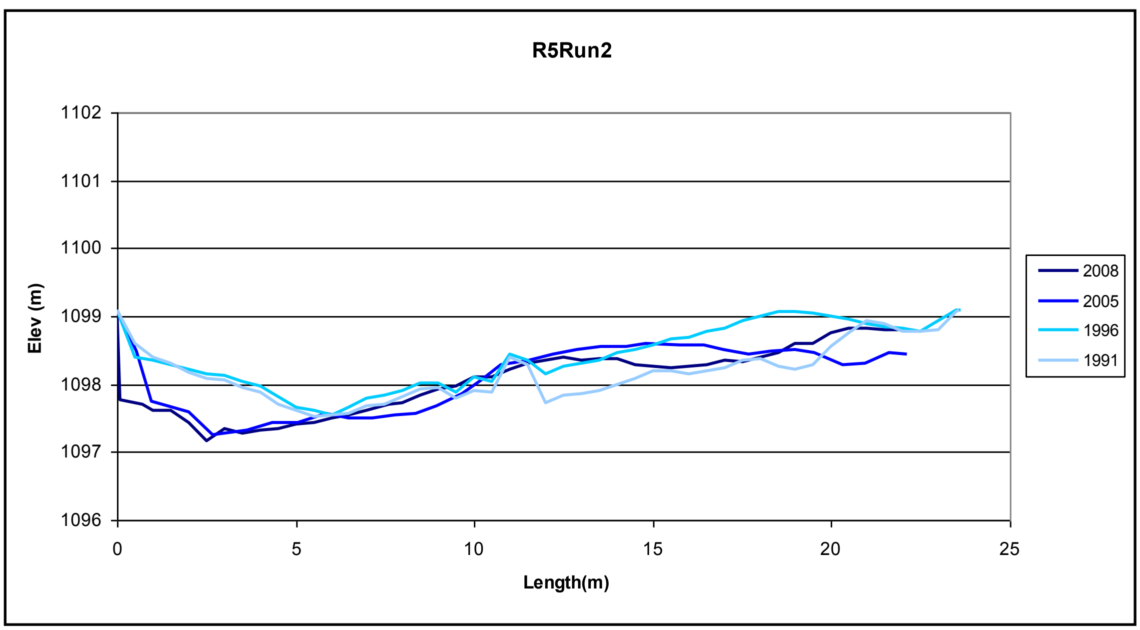


Figure 13: Cross sectional profile of R5Run2 downstream of Big Boulder Creek

The overall trend for cross section R4Rif1 was incision and widening of the channel. Between 1991 and 1996, the cross section aggraded slightly while channel width remained the same. The channel then got deeper from 1996 to 2008. The greatest change in channel profile was between 2005 and 2008 when the channel got about .6m deeper over just 3 years.

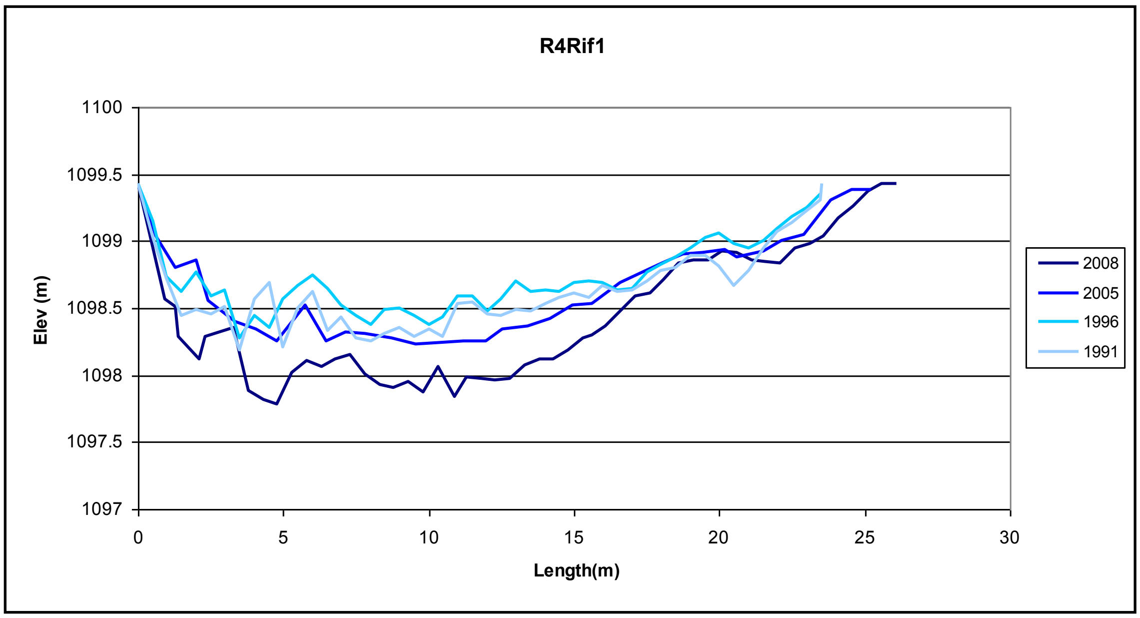


Figure 14: Cross sectional profile of R4Rif1 upstream of Big Boulder Creek.

Cross section R3Run3 shows lateral migration -- the erosion of a cut bank on the right side of the channel and bar aggradation on the left bank (Figure 15). Between 1991 and 1996, there was almost no change in the cross section. Following this period of little change, the right bank retreated by about 4m between 1996 and 2005. At the same time, the bar on the left bank aggraded. By 2008, the right bank retreated another 1.5m and the bar on the left bank continued to aggrade. Channel depth showed no significant change during this survey period.

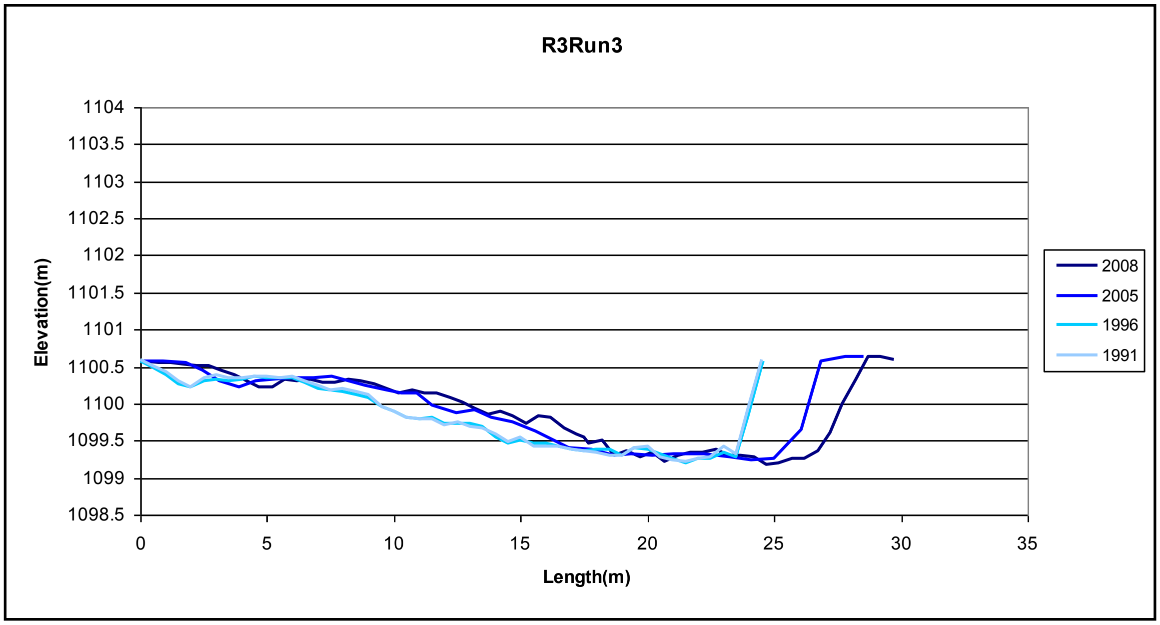


Figure 15: Cross sectional profile of R3Run3 upstream of Big Boulder Creek

R3Rif3 (Figures 11 and 16) shows very little change between 1991 and 1996. From 1996 to 2005, the left bank started to aggrade while the right bank eroded. After 1996 the former thalweg near the right bank aggraded, shifting the thalweg to the left . The right bank narrowed and there was only a small amount of scour on the left bank, causing and an overall narrowing of the channel during this time period. Can you answer Andrew's question on the figure here?

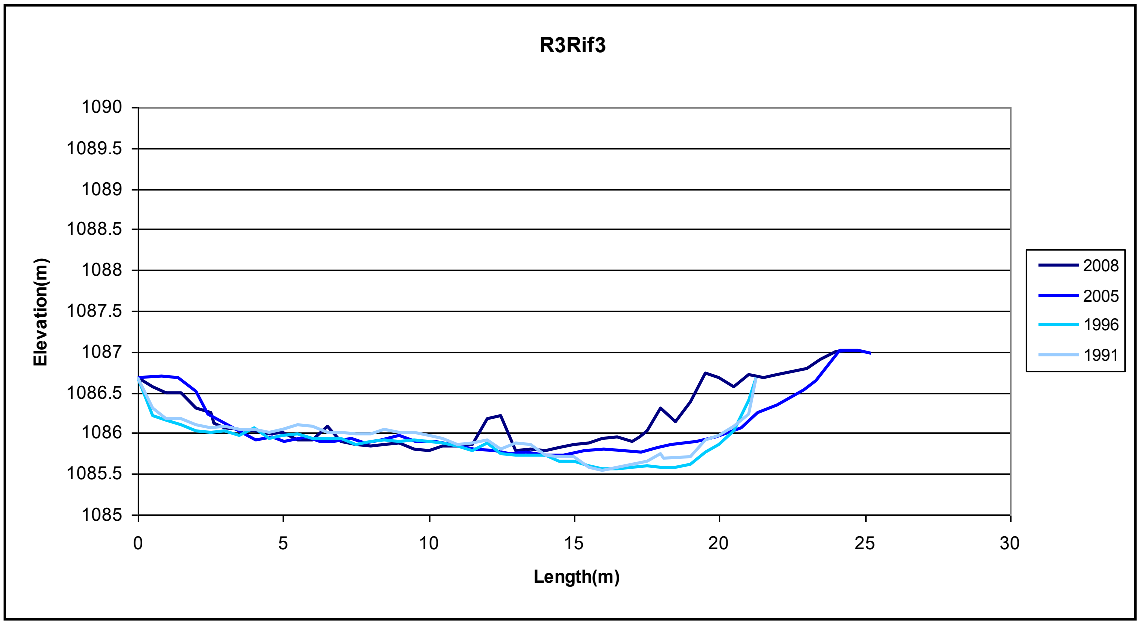


Figure 16: Cross sectional profile of R3Rif3 upstream of Big Boulder Creek

R3Rif4 (Figure 17) had almost no change in the profile between 1991 and 1996. Between 1996 and 2005 however, the right bank was cut away by about 4m. During the three years between 2005 and 2008 erosion of the right cut bank ceased. There is a bar in the center of the cross section that divides the main channel on the right from two side channels on the left. This bar developed between 1996 and 2005. Both side channels and the thalweg show aggradation from 1996 through 2008.

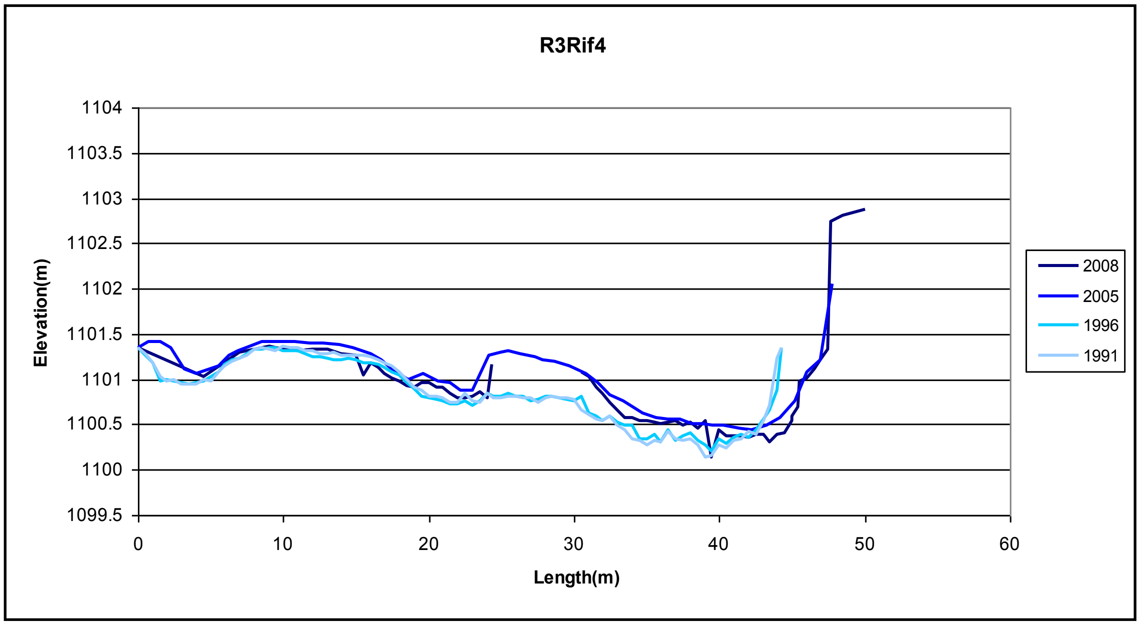


Figure 17: Cross sectional profile of R3Rif4 upstream of Big Boulder Creek

The pre and post flood cross section of R1Rif1 (Figure 18) is located u of the Big Boulder Creek confluence (Figure 11). This cross section was surveyed the summers before and after the flood of 1997 and it follow the incision trend of the other cross sections downstream of Big Boulder Creek. The channel incised by as much as 1m on the left bank. This both widened and deepened the channel. The right bank also appears to have aggraded to the left.

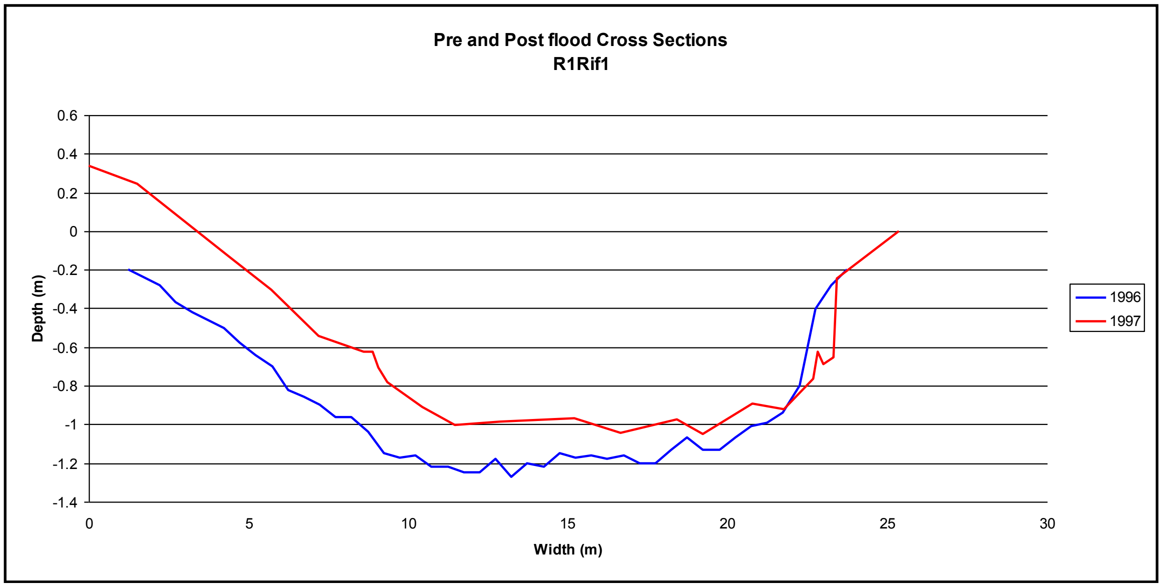


Figure 18: Pre and post flood cross sectional profiles of R1Rif1 downstream of Big Boulder Creek.

The two surveys downstream of Big Boulder Creek (R5Run1 and R5Run2) both incised, while three of the surveys upstream (R3Run3, R3Rif3, and R3Rif4) aggraded over the study period. The exception is R4Rif1 just upstream of Big Boulder Creek which incised over the survey period (Figure 14). The third survey upstream R3Rif4 narrowed while channel depth remained relatively stable. Additionally, the rate of change in the cross sections seemed to increase after 1996. The greatest rate of change occurred between the 1996 and 2005 surveys. This period included the large flood of 1997.

CHAPTER V

DISCUSSION AND CONCLUSIONS

The following sections address my four research questions. The first looks at how channel sinuosity has changed since 1939 and to what extent the channel has laterally migrated. The second addresses whether the TNC management of the property has altered the channel. The third question looks at changes in habitat diversity and possible impacts of the 1997 flood and fire on the cross sectional profile. Finally the fourth question addresses the dominant processes that have influenced the present day channel.

Question 1: Pre-TNC Channel Conditions

Human modifications of the channel and floodplain pushed the river toward the south valley wall and cutoff any secondary channels. Secondary channels had already been cutoff and the channel straightened by the time the first aerial photos became available in 1939. The historical channel location can be seen as scars on the floodplain which may be a few hundred years old. Additionally, the 1939 channel centerline has one side channel that was cut off sometime between 1939 and 1956. Riprap was added along the banks to further stabilize the channels (Figure 5), which has contributed to the reduction in channel migration rates seen over the last 80 years. The sinuosity of the TNC reach decreased after 1939, probably as a consequence of the dredging upstream of the property. The 1939 aerial photo suggests that the channel experienced heavy sedimentation because unlike all other years, water in the channel appeared white with sediment.

Sinuosity was higher on the USFS reach than on the TNC reach. The wider floodplain on the TNC property should provide more room for the channel to meander than on the USFS reach, resulting in a higher sinuosity on the TNC reach, however this is not the case. Different land management practices of the two properties are likely causing this discrepancy. Despite having a larger floodplain, the TNC channel is less sinuous because meanders were cutoff, creating a straight channel along the south side of the valley. This channel is confined by riprap and an old railroad grade along its banks. Unlike the TNC reach, the USFS reach did not have riprap installed. The straightening of the TNC reach (prior to TNC ownership of the preserve) and the cutting off of side channels means that the channel's discharge is forced into a single, shorter and steeper channel. An example of this is the meander seen on the west side of 1939 channel centerline (Figure 7). The map of disturbance features (Figure 5) shows a concrete cutoff wall on the upstream side of the meander. This effectively cut flows off from the meandering channel, creating the straight channel along the south valley wall that we see today. Typically, grazing creates unstable banks which could make the channel more prone to migration because it can move more freely. Since the channel appears to migrate very little over the last 70 years despite the presence of grazing cattle (Figure 7), the greatest factor controlling channel migration on the TNC reach appears to be direct human manipulation of the channel and floodplain through bank stabilizing riprap and railroad grades.

Question 2: The Effects of TNC Management: 1991-1996

Upon purchasing the Dunstan Homestead, the TNC eliminated grazing on the property in order to protect and begin the process of restoring their section of the Middle Fork. The elimination of cattle grazing can potentially have an impact on the morphology of the channel. However, based on the cross sectional profiles, the channel on the TNC reach was relatively stable between 1991 and 1996. The cross sectional profiles showed almost no change during this five year span. For all of the cross sections the period between 1991 and 1996 had the least amount of change (Figures 11-17). It may also take a longer period of time than just the five years between 1991 and 1996 to have significant enough changes in channel vegetation to cause measurable morphological changes. The reestablishment of riparian vegetation may not have a strong influence on the channel morphology over this short time span, but vegetation even in the short term is important for lowering water temperatures and providing cover for fish habitat.

Question 3: Effects of the Summit Fire and the 1997 Flood

The Summit Fire in the summer of 1996, followed by the second largest flood of record in January of 1997, created a potentially significant disturbance event. Responses to this disturbance sequence are seen in large wood loading and channel morphology. The fire burned down from the hills on the north side of the channel and jumped across, scorching part of the south valley wall (Figure 6). With 80% tree mortality the fire created snags along the bank that upon falling could add large woody debris to the channel, thereby improving in stream habitat. The greatest increase in wood in the 2008 survey occurred between Big Boulder Creek and the USFS property right where the fire burned. There was also an addition of wood to the TNC reach from the large woody debris structures that were put in as part of the restoration project, but this did not appear to be the primary source of wood. Much of the wood in the channel here is charred and appears to have fallen from the steep south valley wall. While this increase in wood is a great addition to the river, the habitat survey suggests that it has not altered the morphology of the channel. Based on the habitat survey data, this portion of the reach between Big Boulder Creek and the USFS boundary was relatively unchanged between 1996 and 2008 despite the increase in large wood (Figures 8 and 9).

Figures 14 -17 show the cross sectional profiles upstream of Big Boulder Creek, in the area that received a large influx of wood. The only cross section that showed scour was R4Rif1 (Figures 11 and 14) however the greatest amount of change occurred after 2005, not in the time period after the flood, so this change was unlikely the result of the wood. The lateral migration seen in Figures 15 and 17 between 1996 and 2005 could have been a result of the removal of bank stabilizing vegetation from fire. The lack of vegetation would exacerbate the effects of the flooding in 1997. Overall, the cross sections suggest that the large wood did not have a strong impact on the channel here.

The additions of riprap and the railroad grade are another potentially significant disturbance to the channel. Welcher, in her 1993 report to The Nature Conservancy, found that the straightening of the channel had caused 32cm of incision in the channel since the 1930s. The cross sections showed the greatest amount of scour downstream of

Big Boulder Creek while the upstream cross sections did not change in depth between 1991 and 2008. The riprap and railroad grade effectively armor the banks so the channel cannot migrate laterally or adjust its width in response to increased flows. Downstream of Big Boulder creek where the railroad grade is located and rip rap is abundant (Figure 5), the channel incised after the flood. Upstream of cross section R4Rif1 (Figure 14), the railroad grade shifts away from the channel and there is no riprap (Figure 5). Through the upstream cross sections R3Run3, R3Rif3 and R3Rif4 (Figures 15-17), the channel widened after the flood rather than incising. The habitat unit surveys further support the results of the cross sections. Upstream of the Big Boulder Creek confluence the channel is wider than downstream of the confluence (Table 2), even though theory suggests that the channel should widen with distance downstream. Because the channel is more confined downstream on the TNC property it incises rather than widens and cannot migrate laterally.

The 1996 and 2008 habitat surveys showed a difference in habitat unit at the mouth of Big Boulder Creek. In 1996 prior to the flood, there was a pool directly downstream of the confluence. By 2008 the pool downstream is smaller and a riffle formed at the confluence (Figures 8 and 9). Since the flooding brought cobble sized sediment into the Middle Fork, this likely increased the size of the bar at the Big Boulder Creek confluence. The deposition of this sediment expanded the size of the bar, decreasing the pool size and creating the riffle.

In 2004 the TNC began actively restoring the channel. This has involved removing riprap, digging out pools, and adding large woody debris structures. The impacts of this work are apparent in the habitat unit surveys from 1996 to 2008. Prior to any restoration, the TNC and USFS reaches were very similar, both dominated by long riffles with a few short pools and even fewer glides scattered in between (Figures 8 and 9). Riffles dominated the length of the channel, comprising 75.5% and 73% of the TNC and USFS reaches respectively. By 2008 the TNC and USFS reaches looked very different from one another (Figures 8 and 9). The construction of pools along the TNC reach increased the percentage of channel in pool habitat to 36% and decreased the percentage of riffles to 63% (Table 2). The USFS percentages remained nearly constant from 1996 to 2008 (Table 2). These differences are the result of the restoration work done on the TNC. Descriptions of the restoration and pool construction are found in the attribute table of the habitat survey and show that the new pools are the result of the ongoing restoration projects.

Question 4: Overall Controls of Channel Form and Implications for Restoration

The Middle Fork John Day River has a long history of both human and natural disturbance including mining, logging, grazing, and fire. Based on the results discussed in this thesis it appears that modern rates of change and channel morphology are heavily influenced by rip rap and channelization. Where these human impacts are present, the channel appears less able to migrate laterally or widen in response to increased flows. Additionally, by cutting the flow off to the side channels discharge likely increased in the main channel. As described by Welcher (1993), since the banks were stabilized, the channel incised over time. Additionally, it appears that the channel was relatively stable between 1991 and 1996. This shows that the management changes (i.e. elimination of cattle grazing) implemented by the TNC did not have much of an effect on the morphology of the channel. It is also possible that the time span was not long enough to show the effects, since passive restoration techniques can take many years before the benefits become apparent. The flood did have an impact on the channel causing aggradation downstream and widening upstream. While the flood played an important role, it appears that the way it influenced the channel (incision vs. widening) was a function of the presence and absence of human disturbance features on the floodplain and in the channel.

One of the goals of the Nature Conservancy is to use passive restoration techniques to restore the channel environment. Welcher (1993) suggested that because of the extent of the disturbance, some active restoration may be necessary. The results of this thesis support the idea that some active restoration is necessary. The 2008 habitat surveys show that the greatest change to the TNC reach occurred as a result of the constructed pools and large woody debris structures. If left alone, as the Forest Service reach was, there would have been almost no change over the 12 years between habitat surveys. Restoring flows to the side channels and removing the rip rap would decrease discharge in the main channel which could slow incision and make the channel less prone to scour from large events like the 1997 flood.

Evaluation of Methodology and Data Quality

This study used data from a variety of sources including the Nature Conservancy, the Bureau of Reclamation, the Forest Service, the Oregon Department of Fish and Wildlife, fieldwork from Patricia McDowell, as well my own fieldwork. The conclusions in this study were drawn from cross sectional profiles, aerial photos, habitat unit surveys, field observations and previous literature. Having a variety of data sources and types of data was valuable due to the time frame being studied. Cross sections and habitat surveys were available for the last 20 years in this study area and provide important details of the channel that are not captured in an aerial photo. The benefit of the aerial photos is that they go back to 1939 and they help to provide a context for changes seen in the cross sections and habitat unit surveys. For example logging of the surrounding hillsides, dredging of the floodplain upstream, and sedimentation of the channel can all be seen in the aerial photos, providing clues as to the cause of changes in channel morphology. Additionally, the aerial photos were important for digitizing channel centerlines in order to calculate sinuosity and observe channel migration. The aerial photos and habitat data were both important data sources because this project compares changes to the channel between different landowners (USFS and TNC), and unlike the cross sections, they span both properties,

Having data from so many different sources and time periods means that many different people measured and recorded it, creating the possibility of different biases between samples. With the habitat data for example, the 1996 survey was completed by the Oregon Department of Fish and Wildlife, and the 2008 data were measured by the

Forest Service. Different attributes were measure and unlike the 1996 survey, the 2008 data were not already in a GIS compatible format. Since the habitat unit data were measured by different groups of people with different biases there is inherently some error in the measurements. However, since my study is looking for general trends across the study area and I have other types of data to cross compare it with I believe it is sufficiently accurate to draw the conclusions made in this thesis.

The challenge with the cross sections was that many of the rebar stakes and labels used to mark the sites had been washed away by flooding or appeared to be knocked out while restoration projects were put in. This limited the number of cross sections available for comparison. Through the process of searching for the cross sections I learned the importance of good site selection. If I were to start a similar project from the beginning I would increase the distance between stakes so that they extend farther into the floodplain and are less likely to be washed away. Additionally, I would record the location of the stakes with a GPS and take a photo showing where they are. Ideally, I would try to check on them even during years when cross sections are not measured so that if they start to get loose they could be replaced before disappearing. While this may be time intensive it would help make sure that the cross sections are more accurate and reduce the number of lost cross sections.

The US Forest Service reach upstream was selected in order to compare sites with different management practices in order to see the impacts of the ending grazing on the TNC property. McDowell (2001) showed that channel morphology is heavily influenced by valley width and disturbance history. The valley width in part influenced the disturbance history because the wider valleys were more desirable for private ranching while the narrow valleys became Forest Service land. Considering the difference in valley widths and the effect this has on channel morphology it could have been a poor choice to use the Forest Service reach as a control. This could explain the lower number of habitat units per kilometer on the Forest Service reach compared to the TNC reach (14.4 compared to 17.0) (Table 2). It would also suggest that sinuosity on the Forest Service reach should be lower because of the channel being contained by the valley; but sinuosity was actually higher on the Forest Service reach.

APPENDIX

DYNAMIC SEGMENTATION PROCEEDURE

Data needed to begin:

- A polyline shapefile or line feature class of the stream that you want to dynamically segment your survey data to.
- Data table containing route, unit length, beginning measure, and end measure attributes and all the survey data (ie width, substrate, woody materials, etc) (see Table 1 for an example). This should be saved as a comma delimited file .csv. You have to close your .csv table from excel or it cannot be added to ArcMap.

  - *Route*: this is should be the same number for all of the units. Best to make it the same as the reach number.
  - *Measure*: The route feature class that you will make requires a *Measure* field that has the lengths of the units you want to route to your stream polyline. It is about equal to the Measure_Length field in the survey data table, but since there is inherent error between measuring the length of the channel in the field and the length obtained in GIS they do not match up precisely.

    You adjust your field measurements (Measure_Length) to fit the poly line as follows:

    $Measure_1$= [$Measured\_Length_1$*(length of stream polyline you are routing to)] / (field measured length)… $Measure_2$= [$Measured\_Length_2$*(length of stream polyline you are routing to)] / (field measured length)…etc

    field measured length is the sum of the Measured_Lengths from the survey data table.

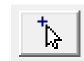
    Another way of looking at it is:
    ($Measured\_Length_1$) / (Field measured length) = (X) / (length of polyline)
    X= *Measure* and is needed so that your survey data fits the polyline

  -*Begin*: this is the distance that the unit starts at. The first unit in the reach should begin at 0.
  $Begin_1$=0…$Begin_2$ = $Begin_1$ + $Measure_1$…$Begin_3$=$Begin_2$+$Measure_2$…etc
  -*End*: this is the distance that the unit ends at.
  End_1=$Measure_1$…End_2=End_1+ $Measure_2$… End_3=End_2+ $Measure_3$…etc

1) Create a new Personal Geodatabase. Right click > New > Personal Geodatabase and give it a name that makes sense.

2) Create a route feature class. Right click geodatabase > New > Feature Class. Give it a name. Check the box for Coordinates include M values. Choose a projection. Leave the XY tolerance as the default. Add a ROUTE field with data type Short Integer. Finish.

3) Add route feature class to a new ArcMap session. Add the stream shapefile. Add your data table.

4) Add the Routing editing tool bar, View > Toolbars > Route Editing.
Open an edit session, Editor > Start Editing, choose the route feature class as your editable layer. Select Task > Create New Feature. Target > your route feature class. Use the black arrow to select the stream shapefile. It should be highlighted now. Zoom to the part of the stream that you want to designate as the start of the route. Select, Make Route from the Route Editing toolbar. A window pops up, click the start point button . Go back to the viewer and click the start of your route which your arrow will snap to when you are close (a circle appears around the start point). Specify that the measure values will be obtained from Measure Field > Shape_Leng.

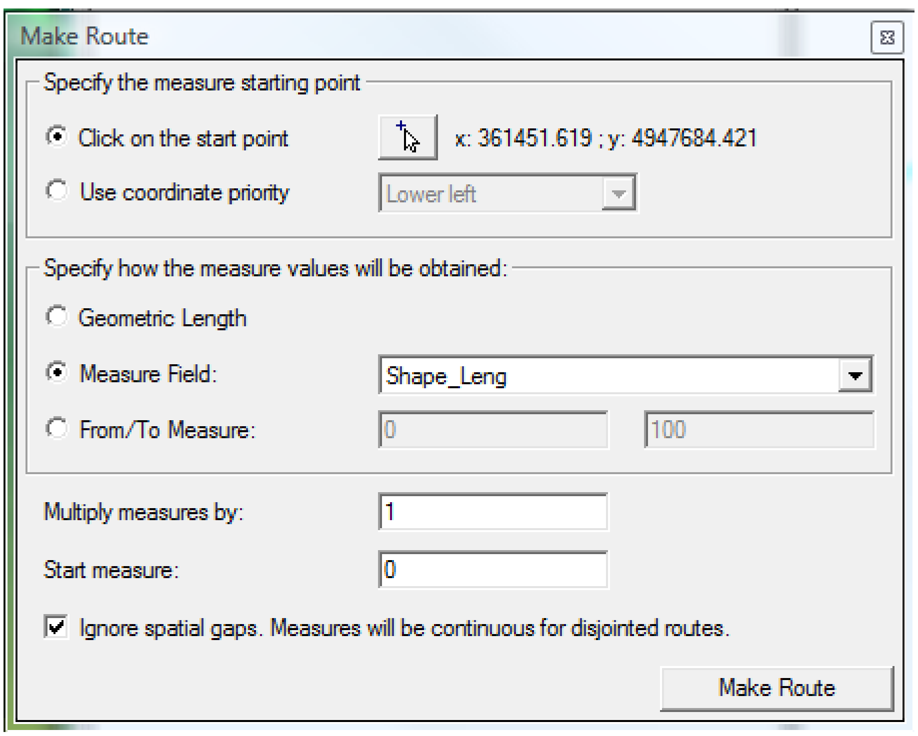


Figure 19: Click on Make Route and the window will disappear.

5) Open the attribute table for your route feature class (you should still be in the editing session). Under the ROUTE attribute replace <NULL> with the route that corresponds to the ROUTE in your data table where you are getting your measures from. End your editing session and choose Save Edits.

6) Right click on the data table > Display Route Events. A window pops up. Your Route Reference is your route feature class. Route Identifier is ROUTE. Event Table is the one you just right clicked on and this should be grayed out. Route Identifier is ROUTE. The table contains Line Events. From-Measure is BEGIN, To-Measure is End. Click OK.

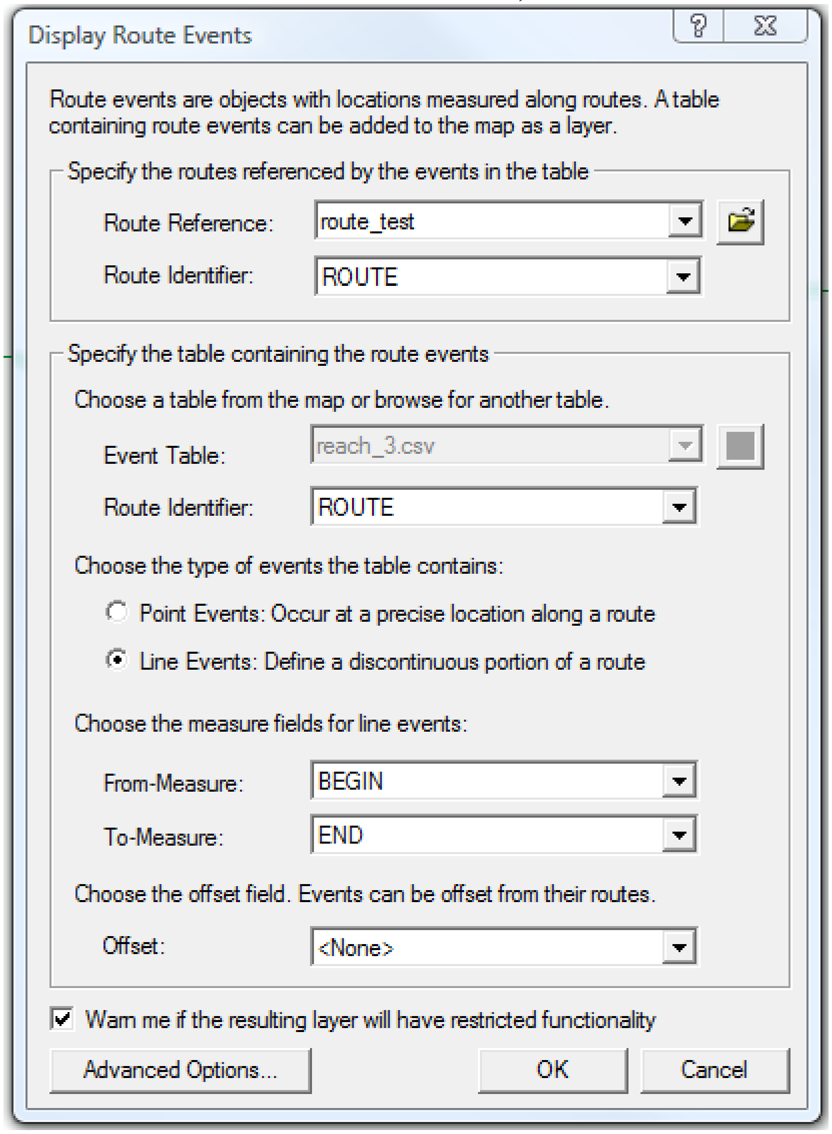


Figure 20: You will be warned that the table does not have an Object-ID Field. Click OK.

7) The routed event will automatically be added. You can now symbolize the attributes from your data table on the stream. You can also export it to a shapefile or Geodatatbase which will give you an Object-ID Field.

Table 5: Sample data table.

ROUTE	HABITAT	REACH	MEASURE	MAX_DEP	AVG_DEP	POOL_CR	BEGIN	END
3	Fast	1	27.432	0.6096	0.42672		0	27.432
3	Slow	2	28.6512	0.762		0.4572	27.432	56.0832
3	Fast	3	42.672	0.762	0.36576		56.0832	98.7552
3	Slow	4	35.9664	0.9144		0.39624	98.7552	134.7216
3	Fast	5	19.5072	0.48768	0.36576		134.7216	154.2288
3	Slow	6	60.96	0.94488		0.39624	154.2288	215.1888
3	Fast	7	152.4	0.64008	0.4572		215.1888	367.5888
3	Slow	8	20.1168	0.762		0.4572	367.5888	387.7056
3	Fast	9	74.9808	0.4572	0.39624		387.7056	462.6864
3	Slow	10	60.0456	0.70104		0.21336	462.6864	522.732
3	Fast	11	73.4568	0.64008	0.39624		522.732	596.1888
3	Slow	12	50.292	0.6096		0.3048	596.1888	646.4808
3	Fast	13	100.2792	0.64008	0.36576		646.4808	746.76
3	Slow	14	60.6552	0.64008		0.24384	746.76	807.4152
3	Fast	15	43.2816	0.54864	0.42672		807.4152	850.6968
3	Slow	16	46.3296	0.762		0.39624	850.6968	897.0264
3	Fast	17	17.0688	0.4572	0.24384		897.0264	914.0952
3	Slow	18	60.96	0.70104		0.24384	914.0952	975.0552
3	Slow	19	58.5216	0.97536		0.27432	975.0552	1033.577
3	Fast	20	10.9728	0.42672	0.3048		1033.577	1044.55
3	Slow	21	30.48	1.0668		0.33528	1044.55	1075.03
3	Fast	22	126.1872	0.67056	0.39624		1075.03	1201.217
3	Slow	23	21.0312	0.73152		0.36576	1201.217	1222.248
3	Fast	24	67.056	0.42672	0.24384		1222.248	1289.304
3	Slow	25	68.8848	1.3716		0.27432	1289.304	1358.189
3	Fast	26	27.1272	0.4572	0.3048		1358.189	1385.316
3	Slow	27	78.6384	0.67056		0.24384	1385.316	1463.954
3	Slow	28	35.052	0.73152		0.24384	1463.954	1499.006
3	Fast	29	28.3464	0.54864	0.27432		1499.006	1527.353
3	Slow	30	35.6616	0.88392		0.3048	1527.353	1563.014
3	Fast	31	54.864	0.42672	0.36576		1563.014	1617.878
3	Slow	32	44.5008	0.73152		0.3048	1617.878	1662.379
3	Fast	33	68.2752	0.51816	0.39624		1662.379	1730.654
3	Slow	34	60.96	0.73152		0.39624	1730.654	1791.614
3	Fast	35	170.688	0.51816	0.42672		1791.614	1962.302
3	Fast	36	152.4	0.54864	0.4572		1962.302	2114.702
3	Fast	37	117.348	0.57912	0.42672		2114.702	2232.05

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